ASD-TR-71-2

AD 727051

RESEARCH, DESIGN, FABRICATION, AND FIELD TESTING OF A NINETY (90) FOOT SPAN, TWO (2) ARCH EVALUATION SEGMENT. AIRCRAFT MAINTENANCE HANGAR

JAMES M. ALEXANDER

LAWRENCE E. SPRECKELMEIER

BAHRAM BAHRAMIAN

University of Cincinnati

TECHNICAL REPORT ASD-TR-71-2

FEBRUARY 1971

This document has been approved for public release and sale; its distribution is unlimited.

AIR MOBILITY PROGRAM OFFICE
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

149

BLANK PAGE

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

Many of the items compared in this report were commercial items that were not developed or manufactured to meet any government specification. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

November 1970

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Design Research Collaborative, University of Cincinnati, 3333 Vine St., Suite 400, Cinti, Ohio 45220	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
RESEARCH, DESIGN, FABRICATION, AND FIELD TESTING OF A NINETY (90) FOOT SPAN, TWO (2) ARCH EVALUATION SEGMENT, AIRCRAFT MAINTENANCE HANGAR

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final Technical Report

5. AUTHOR(S) *(First name, middle initial, last name)*
James M. Alexander
Lawrence E. Spreckelmeier
Bahram Bahramian

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February, 1971		

8a. CONTRACT OR GRANT NO. AF33(615)3242	9a. ORIGINATOR'S REPORT NUMBER(S) (Unassigned)
b. PROJECT NO.	
c. 3782	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ASD-TR-71-2
d.	

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Mobility Program Office, Deputy for Tactical Warfare, Aeronautical Systems Divisions, Wright-Patterson AFB, Ohio 45433

13. ABSTRACT
A lightweight, 100% recoverable, air-transportable hangar, large enough to accommodate any aircraft up to the size represented by the F-15 and F-111 is needed by the Air Force as part of the inventory of mobility equipment.

The concept utilized in the ninety (90) foot span hangar is the same basic system used in the fifty-eight (58) foot span hangar. The concept utilizes sectional arches of aluminum I-beams and 3/4" thick modular sandwich panels of polystyrene foam or paper honeycomb faced with sheet aluminum. Arch segments are connected with pairs of aluminum hinges, and the adjacent panels are fastened to the beams with camlocks. Variable length spacers between the arches allow for adjustment to minor terrain variations.

A full size two-arch evaluation segment was constructed and field tested.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Lightweight high-mobility ninety (90) foot span, two (2) arch evaluation segment, aircraft maintenance hangar, utilizing sandwich panels and aluminum I-beams.						

RESEARCH, DESIGN, FABRICATION, AND FIELD TESTING OF A NINETY (90) FOOT SPAN, TWO (2) ARCH EVALUATION SEGMENT. AIRCRAFT MAINTENANCE HANGAR

JAMES M. ALEXANDER
LAWRENCE E. SPRECKELMEIER
BAHRAM BAHRAMIAN
University of Cincinnati

FOREWORD

Technical Report ASD-TR-70-26, Vol I, was the first report under Contract AF33(615)3242. This report is a continuation of the work under the same contract. It covers all work performed under the basic contract and modifications S/A #11, 25 February 1969 and S/A #16, 8 October, 1969, with the following exception:

> Work directed toward the completion of and the final reporting on the 58' x 80' Portable Aircraft Maintenance Dock under contract AF33(615) 3242. This work was reported in Volume I of the final report of the contract.

Work conducted between 15 October 1969 and 1 September 1970 is covered by this report.

Work was performed at the College of Design, Architecture and Art of the University of Cincinnati by the Design Research Collaborative.

This report was prepared by Professor James M. Alexander of the Department of Industrial Design, Principal Investigators, Lawrence E. Spreckelmeier, Project Leader, David L. Hunt and Dr. Bahram Bahramian, Engineering Consultant.

In addition to the authors, the following contributed significantly to the work under the contract: Research Assistant Jack R. Farrah and several upperclass co-op students of the college.

The work performed under the contract was administered under the direction of the Air Mobility Program Office, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio The Air Force Technical Monitors were Mr. Milton Bric'son and Captain Richard W. Matzko.

This work contains no classified information.

This report was submitted by the authors, James M. Alexander, Lawrence E. Spreckelmeier, David L. Hunt and Dr. Bahram Bahramian, November 1970.

This technical report has been reviewed and is approved.

Wendall C. Bauman, Lt Col, USAF
Dep. Director, Bare Base Equip SPO
Deputy for Subsystems Management

ABSTRACT

A lightweight, one hundred per cent recoverable air-transportable maintenance hangar large enough to accommodate any aircraft up to the size represented by the F-15 and F-111 is needed by the Air Force as part of the inventory of mobility equipment.

The concept utilized in the ninety (90) foot span hangar is the same basic system used in the fifty-eight (58) foot span hangar. The concept employs sectional arches of aluminum I-beams and 3/4" thick modular sandwich panels of polystyrene foam or paper honeycomb faced with sheet aluminum. Arch segments are connected with pairs of aluminum hinges, and the panels are fastened to the beams with camlocks. Variable length spacers between arches and waterproof fabric flashing allow for adjustment to minor terrain variations.

A full size two-arch evaluation segment was constructed and field tested.

BLANK PAGE

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I

INTRODUCTION

The concept of an Air Force "high mobility" capability has been in existence for several years. Several types of unique structures have been developed to meet the varied needs of the Air Force. One of the needs that has emerged recently is for the development of a lightweight air-transportable maintenance hangar large enough to accommodate any aircraft up to the size represented by the F-15 and F-111.

Such a structure would cover almost 8,544 square feet as compared to the almost 4,600 square feet of the earlier fifty-eight (58) foot span hangar.

Under an amendment to Contract AF33(615)3242, the University of Cincinnati developed, built, and recently delivered to the Air Force, two evaluation arches of a span and configuration to accommodate aircraft with a tail height up to twenty (20) feet and a wing span up to seventy-one (71) feet.

The work under this contract was performed by a group within the College of Design, Architecture and Art currently designated as the Design Research Collaborative. Composition of the group involves Industrial Design and Architecture faculty members, graduates, co-operative students from the Departments of Industrial Design, Architecture, and Mechanical Engineering, and a consulting Civil Engineer.

Organization of this report is essentially along chronological lines. It deals first with a technical discussion of components and the erection sequence of the ninety (90) foot span. The report then deals with the prototype fabrication and subcontracting along with the field testing of the two arch evaluation segment. Appropriate detailed structural analyses are incorporated within the report and as appendices to the report.

BLANK PAGE

II

DEFINITION, BACKGROUND AND OBJECTIVES OF THE PROBLEM

A. DEFINITION AND BACKGROUND

The two (2) arch evaluation segment is the front and rear sections of the proposed ten (10) arch prototype maintenance hangar. The statement of work governing the design of the nominal ninety (90) foot span aircraft maintenance shelter includes the provision that "The shelter shall use, if possible, components used in the smaller fifty-eight (58) foot span aircraft shelter". (Fig. 1)

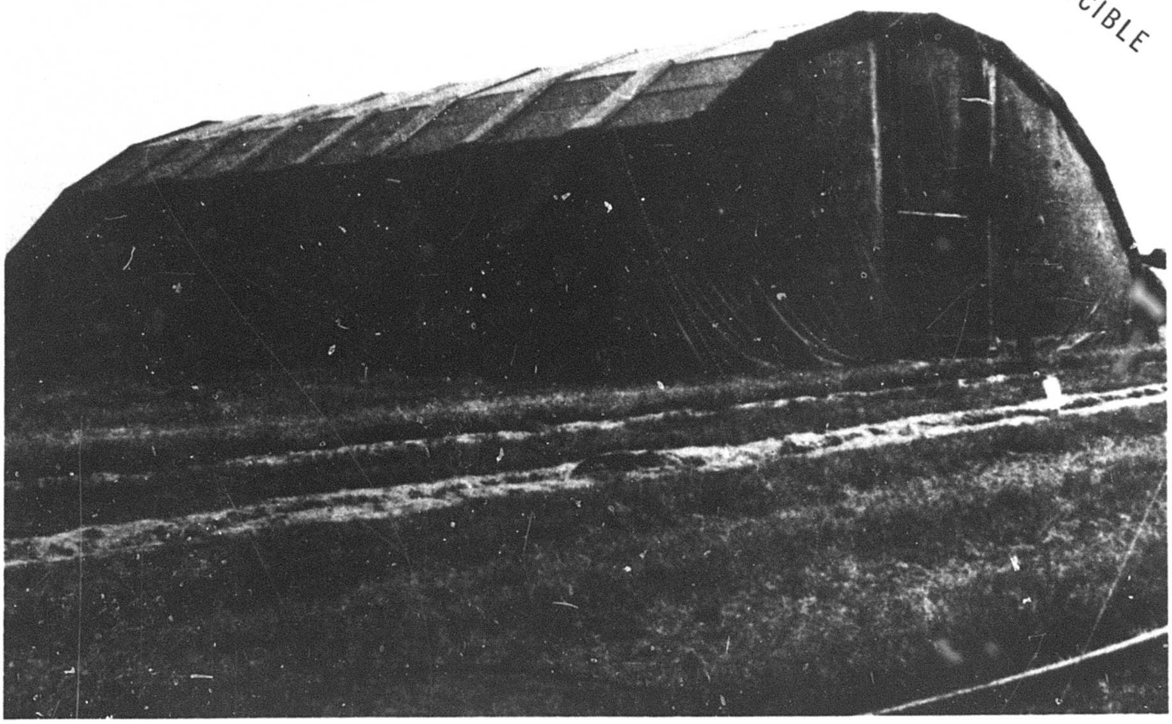


Figure 1. Fifty-eight (58) Foot Span Hangar

In accord with this provision, an adaptation of the structural sandwich panel developed for the fifty-eight (58) foot span hangar was used in the ninety (90) foot span design. Similarly, subject only to minor modification, such items as the lockdown base plates, the adjustable spacer bars between adjacent arches, the beam clamps, electrical system and tool box were of the same design.

The increased span (from nominal fifty-eight (58) feet to nominal ninety (90) feet) and the resultant greater stresses dictated substantial changes in many areas. These included (1) the beam section and hinges used in the basic structural arch, (2) the adjustable base pads supporting the arches, (3) the addition of a lower arch at the end walls, and (4) the fabric end walls (both openable and fixed).

Each arch segment consists of thirteen (13) double panel assemblies, two (2) single or ground panel assemblies, twenty-eight (28) main arch beams, and ten (10) lower arch beams. The two arches are erected independently and connected by expanding braces called "spacers".

B. OBJECTIVES

The objective of this effort was to design an aircraft maintenance shelter for the F-111 aircraft, using components employed in the smaller F-4 aircraft shelter. The configuration was to be as follows:

1. Dimensions: The width at an eight (8) foot height was to be seventy-five (75) foot minimum, the length shall be eighty-six (86) foot minimum and twenty (20) foot minimum center height.

2. Package Weight: 20,000 pounds was to be a design goal for the F-111 hangar.

3. Package Cube: the package volume shall be 1,800 cubic feet as a design goal.

4. Doors and End Walls: The contractor was to:

    a. provide one (1) full-width, full-height flap, drape or accordian door of fabric or other flexible material.

    b. Provide one (1) fixed fabric end wall with the necessary ties, reinforcements, anchorage and other fasteners.

c. Provide one (1) pass door approximately 3' x 7' and one truck door 9' x 9' in the fixed fabric end wall. Interchangeability of the full-width full-height doors and the end walls was a goal.

5. Foundation Beam, Pads, or Base Plates: The contractor was to provide prefabricated lightweight units to provide adequate support and leveling for the shelters and test section. It was also to have the capability of aligning the arches and anchoring the structure to the ground.

6. Connectors: All connectors were to be selected or designed and fabricated on the basis of simplicity, ease of operation, durability, high strength-weight ratio, and economy.

7. Insulation: The fabric door was to contain insulation to reduce heat transfer.

8. Color: The shelter was to be olive drab or camouflage.

9. Operational Life: The shelter was to have a fifteen (15) year shelf life in the disassembled and packaged state. The shelter was to have the capability of being erected twice a year. It was to have a minimum erected life of five (5) years.

10. Cost: The shelter was to have as a design goal, a unit cost of $89,000.00 or less per shelter in quantities of fifty (50) units.

11. Erection Time: The erection time was to be 175 man-hours as a design goal.

12. Loads: The loads were to be sixty-five (65) miles per hour steady wind, and ninety (90) miles per hour wind gust, at thirty (30) feet and/or twenty (20) pounds per square foot on the roof area as a design goal.

13. Blackout Facilities: Any vision panels or windows were to be equipped with blackout devices.

14. Electric Lights and Power: The shelter was to include eighteen (18) light outlets for 150 watt bulbs and eighteen (18) convenience outlets, 120V potential, together with necessary light switches and wiring to attach to incoming service, for each kit. Each shelter kit was also to include twenty-two (22) 150 watt bulbs for use with outlets.

15. Erection Equipment: All shelter kits were to include all the necessary apparatus needed to erect the shelter.

16. Packaging: The packaged shelter and erection equipment was to conform to the 463L pallet system as installed in the C-130E aircraft.

17. Repair Kit: Provide kits to repair damaged panels and high-wear rate hardware items.

18. Heat Resistance: All structural adhesives and components were to have the capability of withstanding daily temperatures of 200° F as a design goal.

After preliminary study of the F-4 hangar components, questions arose as to how many of the components of the F-4 hangar could be used or adapted. The evaluation proposed a two (2) arch segment was to be fabricated. The following items were to be designed and built:

1. Arches: Two (2) complete arches with associated counter-flashing and hardware.

2. Openable Fabric End Wall: Fabricate one (1) end wall door and associated hardware. It must be wide enough to allow passage of the F-111 with the wings extended.

3. Fixed Fabric End Wall: Fabricate one (1) fixed fabric end wall and associated hardware. It must contain one (1) 9' x 9' truck door and one (1) personnel door.

4. Erection Equipment: All equipment required to erect the hangar was to be furnished.

III

TECHNICAL DISCUSSION

A. SITE CONSIDERATION

Prior to the erection of the ninety (90) foot span hangar, certain site considerations should be determined.

Soil on which the shelter is to be erected must be capable of withstanding one and one-half (1.5) tons per square foot of compressive load and should be capable of restraining arrowhead anchors, or similar anchoring devices, for a load not less than 4,000 pounds.

It is preferable that the site be as level as possible for ease of erection. A maximum rise of one (1) inch in a ten (10) foot run.

If the shelter is to be erected on normal ground, drainage should be provided for as follows:

1. Determine shelter floor size. From one foot inside perimeter, lay down a five foot wide strip of either 1/4 inch of fiberglass and resin or a 1/2 inch thick strip of asphalt. This may be done around the entire perimeter or on the long sides only. (Fig. 2)

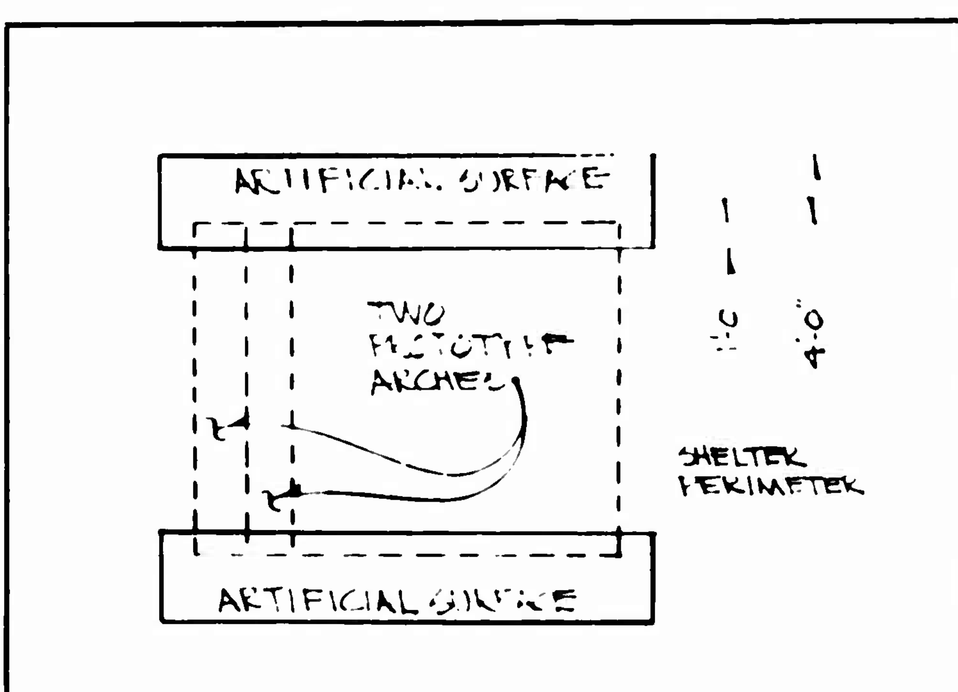


Figure 2. Artificial Surface and Hangar Floor Size Layout

2. Erect shelter

3. At the outside edges of the artificial surfaces, dig a trench with a sloped side, 1'-6" to 2'-0" wide and at least 8" deep. (Fig. 3)

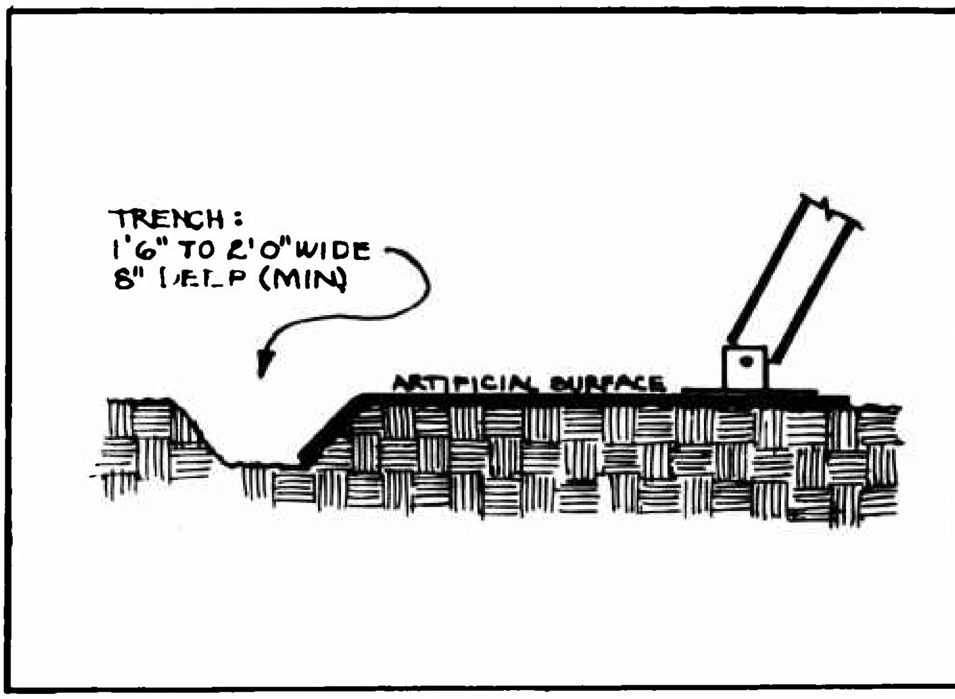


Figure 3. Drainage Trench

Apply either fiberglass or asphalt to the side of the trench towards the shelter.

For erecting the shelter on a prepared surface (fiberglass, black top or concrete), remove the angles from the bottom of the base pads and bolt the pads to lead anchors, or drive arrowhead anchors and stakes through the flexible surface. For erecting the shelter on rocky ground or packed soil, drive explosive type anchors.

In orienting the shelter for the most efficient operation, position the long dimension of the shelter perpendicular to the prevailing wind. (Fig. 4)

B. PACKAGING

The ninety (90) foot span hangar is packaged on three (3) 463L pallets measuring 108" x 88". (Fig. 5)

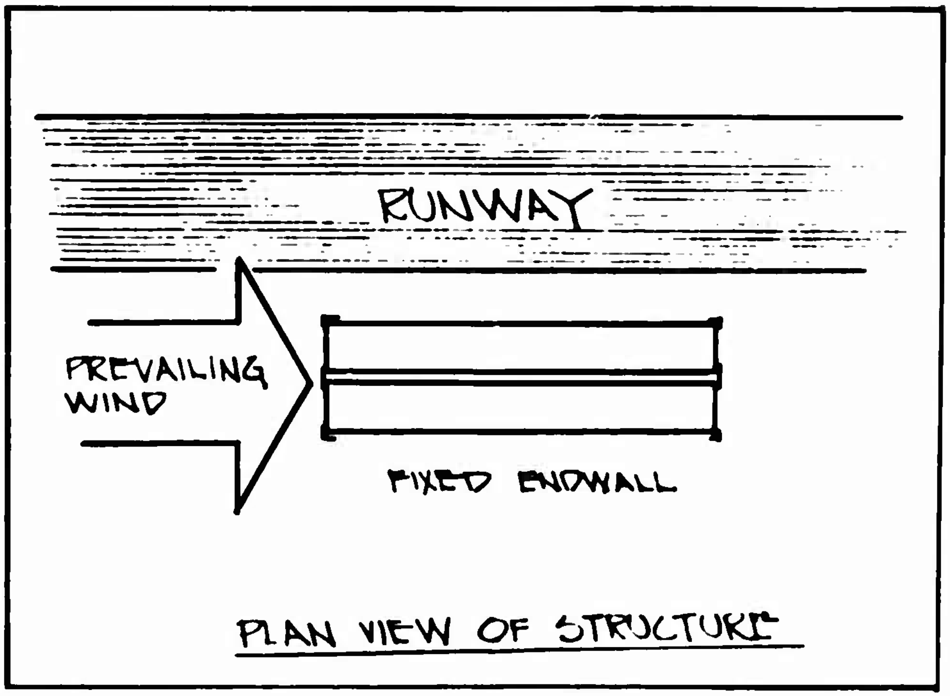


Figure 4. Shelter Orientation

Figure 5. Packaged Ninety (90) Foot Span Evaluation Segment

A general description of what is contained within each package and its general location appears on the drawings (Fig. 6, 7 and 8). This order should also be used when repackaging the shelter.

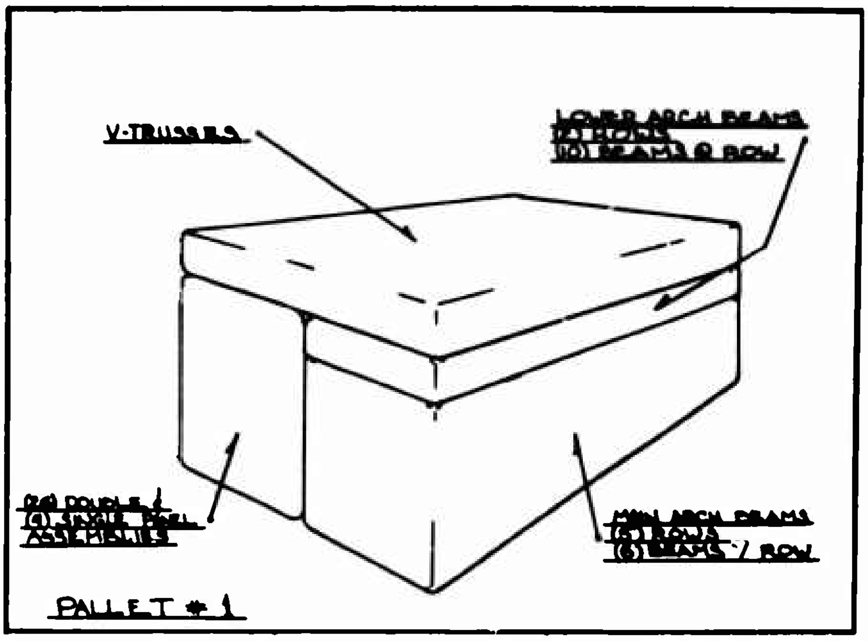


Figure 6. Component Packaging, Pallet Number One

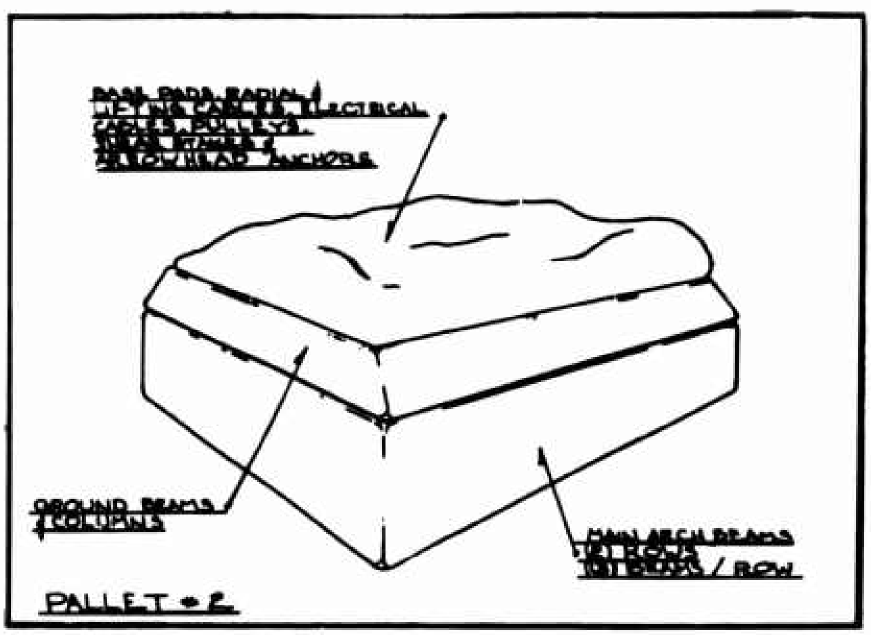


Figure 7. Component Packaging, Pallet Number Two

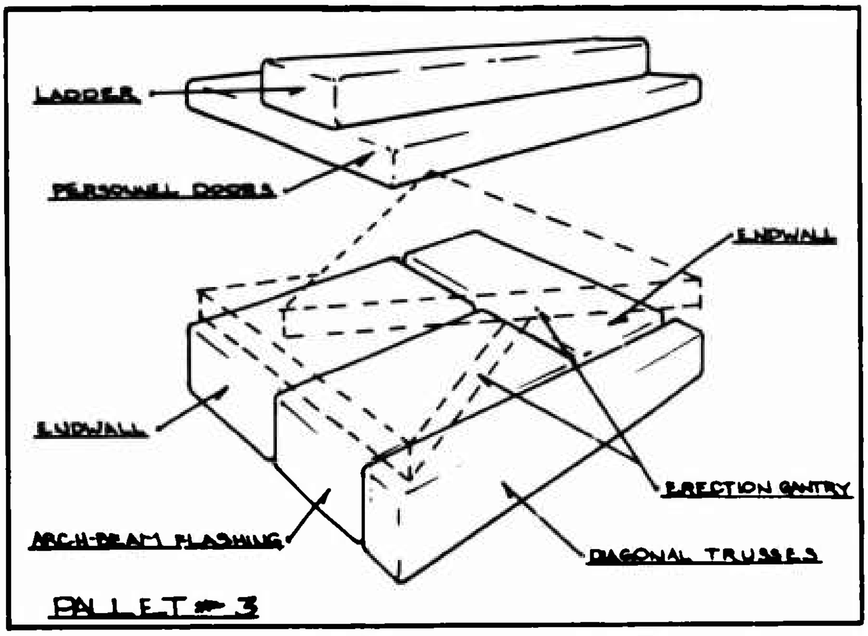


Figure 8. Component Packaging, Pallet Number Three

C. BASE PAD LAYOUT, ANCHORING AND LEVELING

After establishing the desired position of the openable fabric end wall, locate the single base pads of the openable end wall arch with the long leg of the layout cable. (Fig. 9)

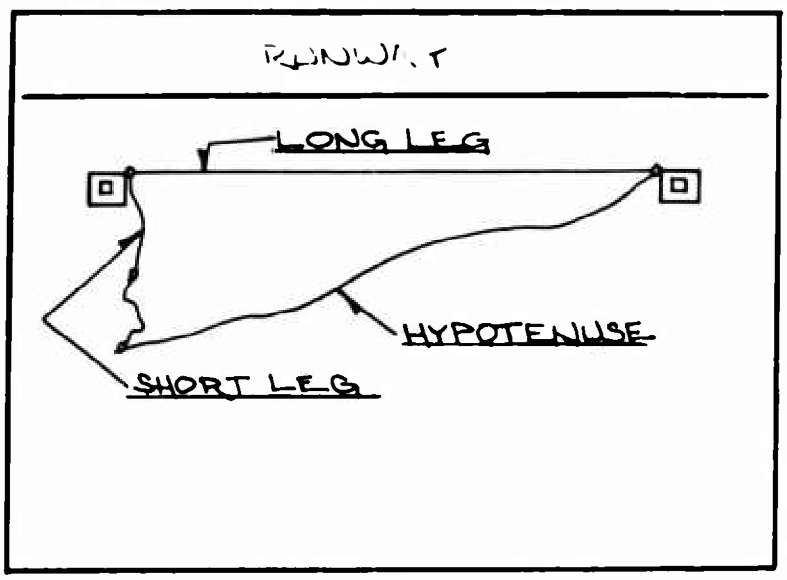


Figure 9. Base Pad Orientation and Layout Cable Use

These pads are initially positioned with the help of angles on the bottom of the pads. The angles are driven into the ground with the foot or a sledge hammer. Eyebolts, located on the layout cable, are then driven through the outside shear stake holes. The cable is pulled taut at the corner of the short leg and the hypotenuse leg to locate the first corner base pad of the fixed fabric end wall. (Fig. 10)

The intermediate double base pad is located by placing the center eyebolt of the short leg through the center inside shear stake hole. (Fig. 11)

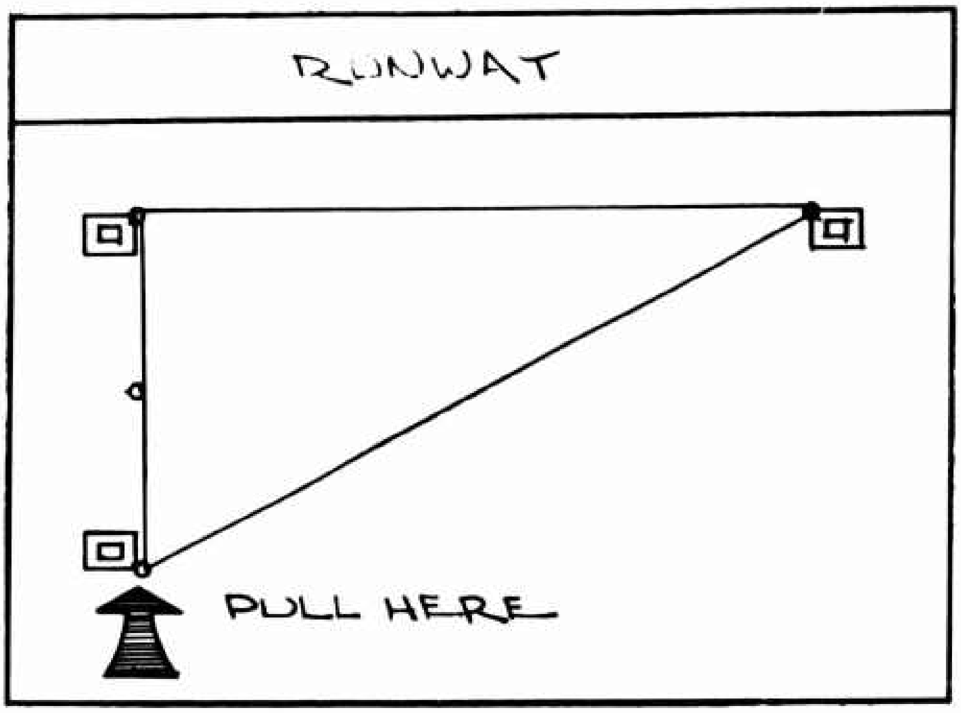


Figure 10. Openable End Wall Base Pad Positioning

Ground angles placed between the base pads serve as a secondary spacing check and serve as a means for closing out the bottom panel flashing. (Fig. 12)

The three initially positioned base pads are staked down with 24" shear stakes.

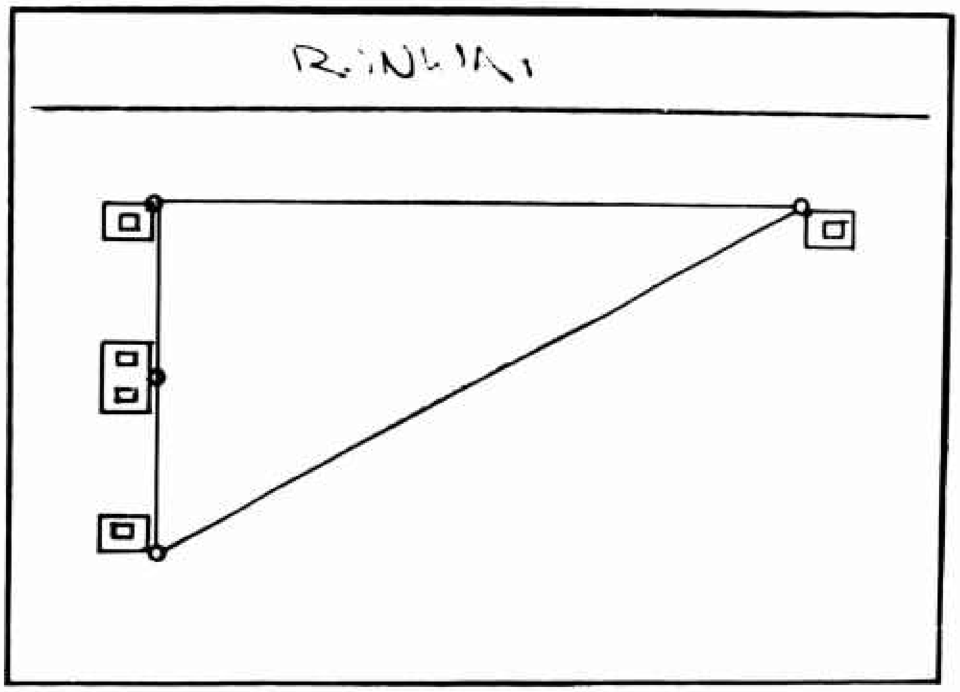


Figure 11. Double Base Pad Positioning

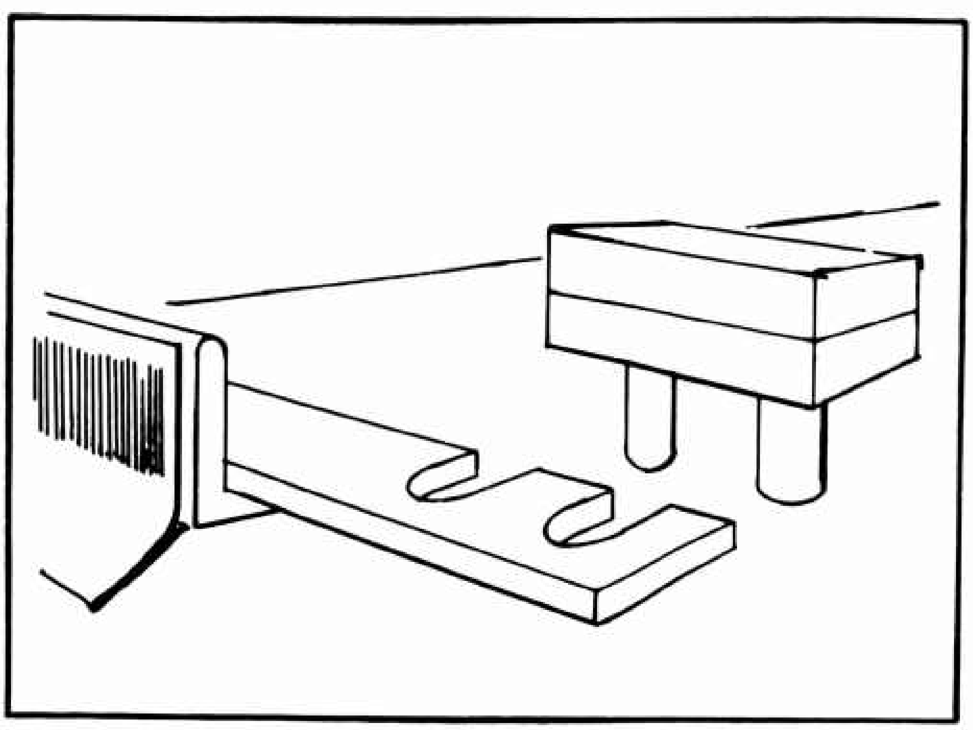


Figure 12. Ground Angle Attachment

The other two (2) base pads are positioned by rotating the layout cable to the opposite position and locating the single pad first. After the double pad is positioned, the ground angles are attached and both pads are staked down. (Fig. 13)

Anchoring the base pads in normal earth conditions requires four (4) arrowhead anchors per base pad and a gasoline powered driving apparatus. (Fig. 14) The anchors are positioned opposite the cable clamps on the base pad. (Fig. 15)

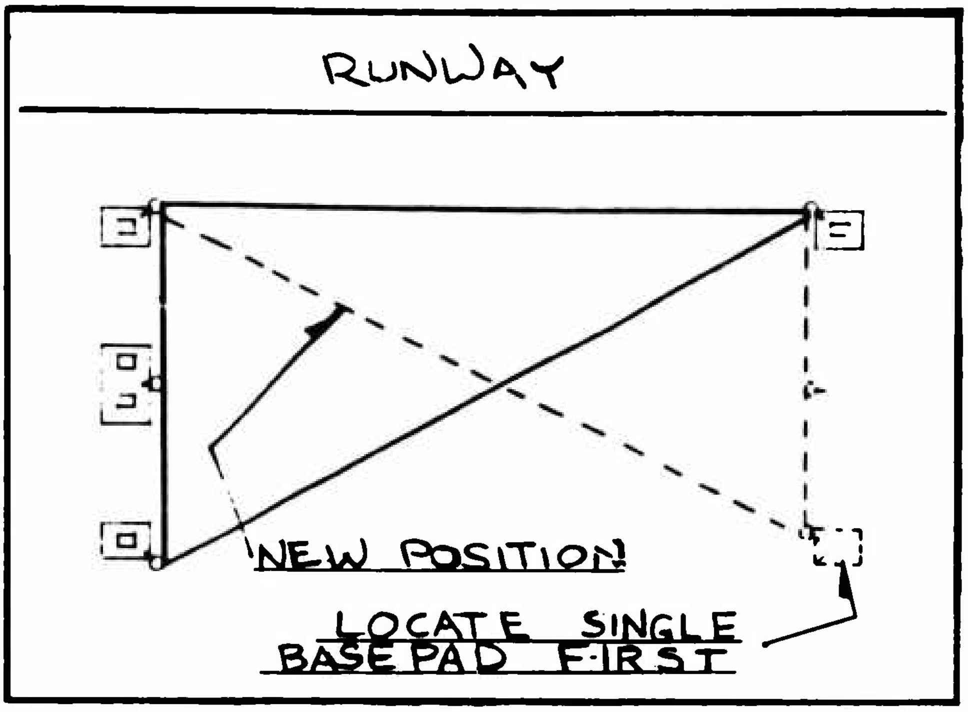


Figure 13. Rotating Layout Cable to New Position

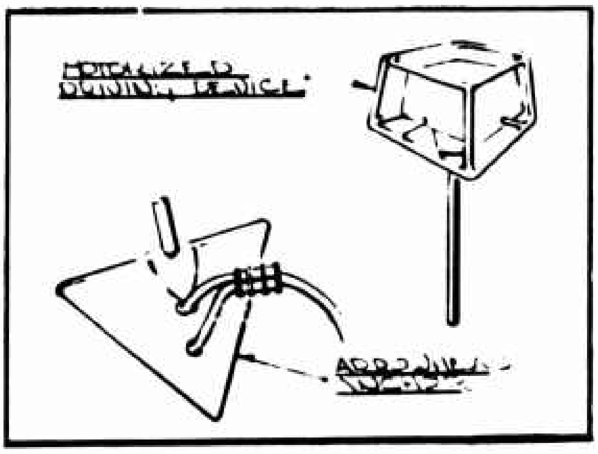


Figure 14. Arrowhead Anchor Driving Device

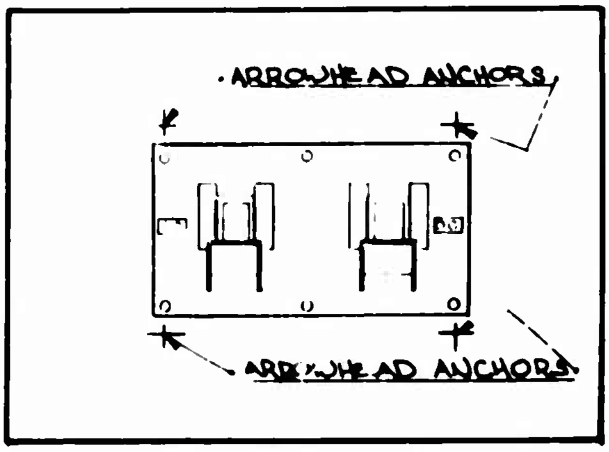


Figure 15. Arrowhead Anchor Position

Each anchor is driven approximately two (2) inches from the edge of the pad and deep enough to allow three (3) to six (6) inches of cable to extend beyond the clamp. (Fig. 16)

The anchors now must be upset, tightened and clamped into place. A large jack tool performs the upsetting. A cable tensioning device uses clamps and a spreading action to tighten the cables, firmly positioning the base pads. (Fig. 17, 18, 19, 20, 21, and 22)

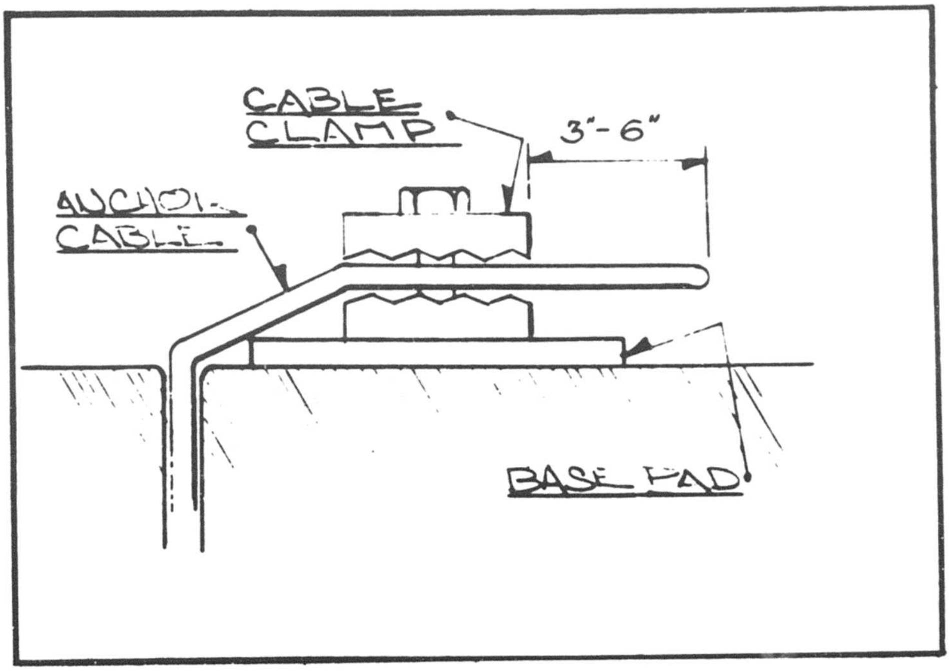


Figure 16. Measuring Arrowhead Anchor Cable

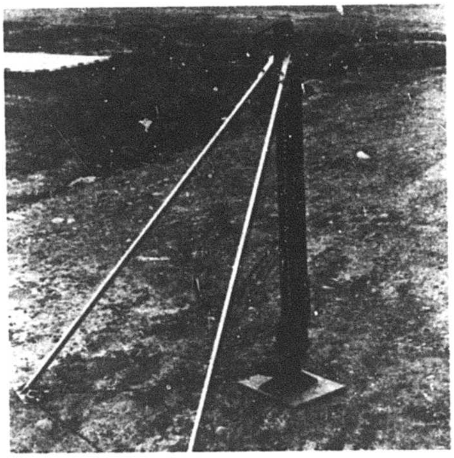


Figure 17. Arrowhead Upsetting Jack

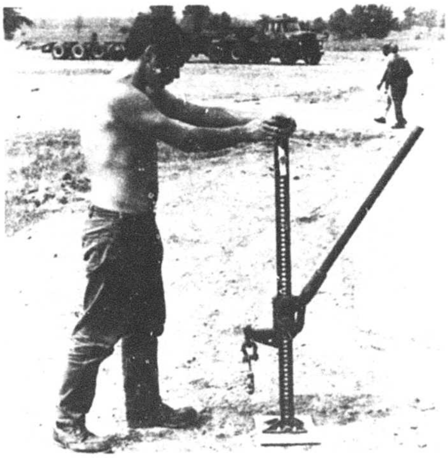


Figure 18. Arrowhead Upsetting Jack - Hand Held

Figure 19. Cable Clamp

Figure 20. Arrowhead Anchor Being Upset

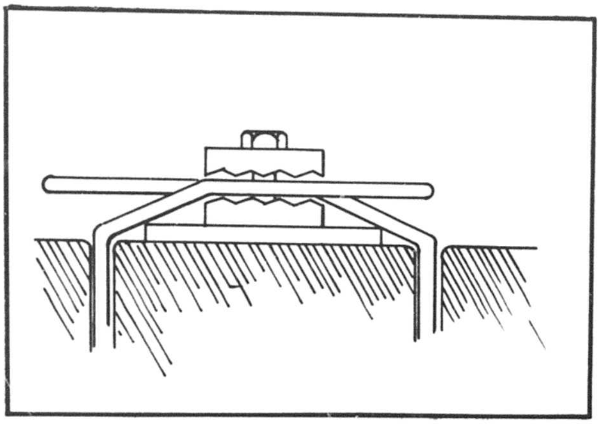


Figure 21. Threading of Arrowhead Anchor Cables

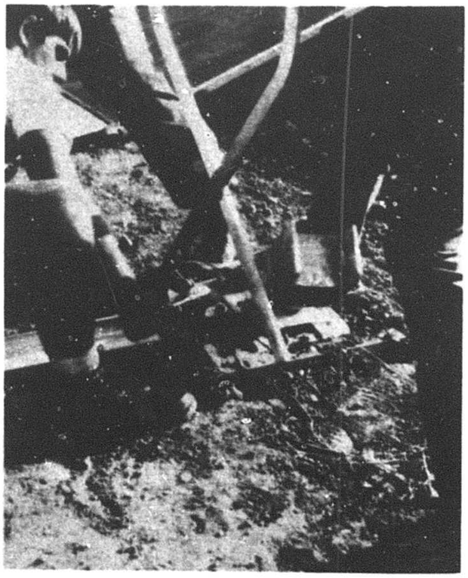


Figure 22. Cable Tensioning Device

Leveling and Alignment

Both single and double base pads have two adjustments used in leveling. The first is a front-back adjustment provided on the surface of the base plate. The second is a vertical adjustment made by a large threaded shaft. (Fig. 23)

The leveling involves a series of three beams attached together to form a large "straight-edge".

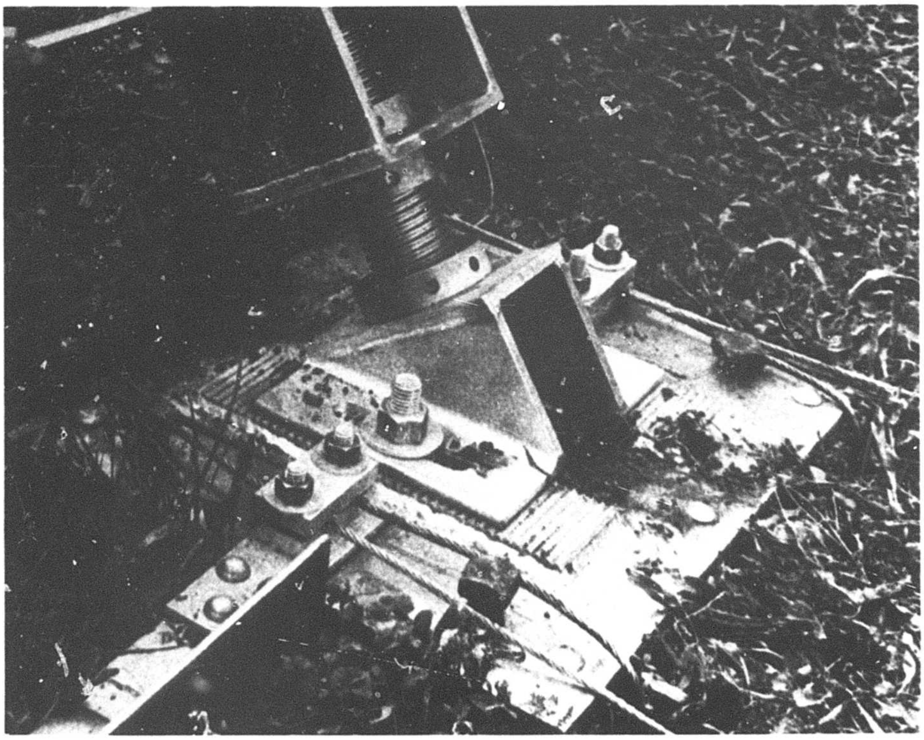


Figure 23. Base Pad Adjustments

The assembly is placed against the clevises. They are then adjusted so that the sides rest against the sides of the "straight-edge". (Fig. 24) This establishes the front-back alignment.

The vertical alignment is made by placing the assembly on top of the clevises and adjusting the threaded shaft until all three touch the bottom of the "straight-edge". (Fig. 25)

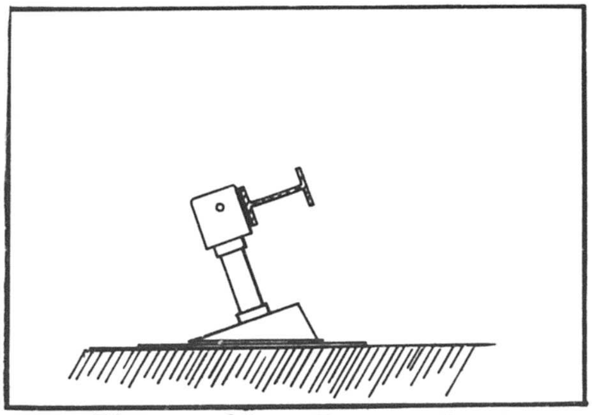


Figure 24. Front - Back Alignment of Base Pads

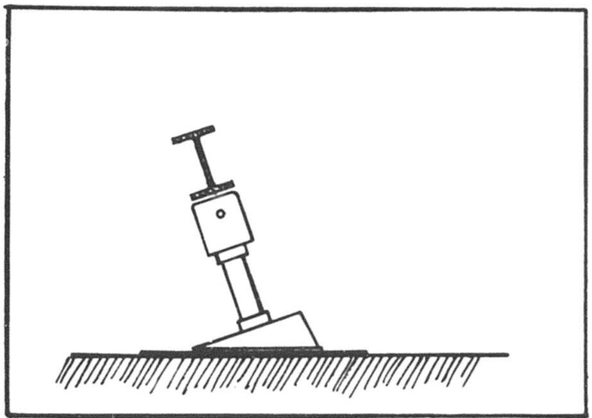


Figure 25. Vertical Alignment of Base Pads

D. ERECTION GANTRY

For shipment the erection gantry breaks down into three pieces.

An overhead beam assembly consisting of an "I" beam and standard hinges is assembled. "A" frame legs and diagonal braces are assembled to form both sides of the frame. (Fig. 26)

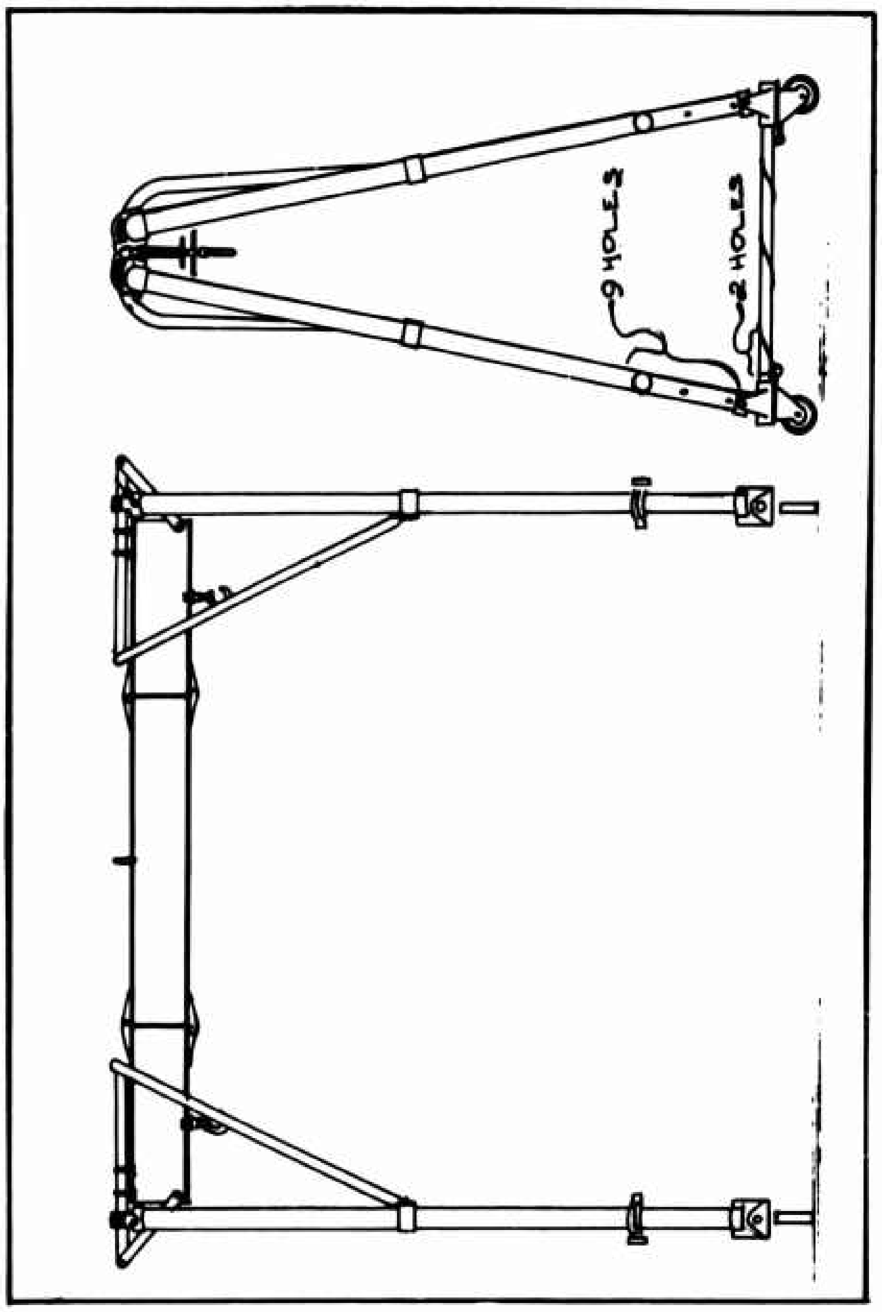


Figure 26. Erection Gantry

Two (2) chain hoists are placed on the lifting hooks underneath the "I" beam member. They provide a very safe and efficient means for lifting the arch during the erection sequence.

E. ARCH ERECTION

This prototype shelter contains two (2) arches, a fixed fabric end wall arch and an openable fabric end wall arch. The sequence is shown in (Fig. 27).

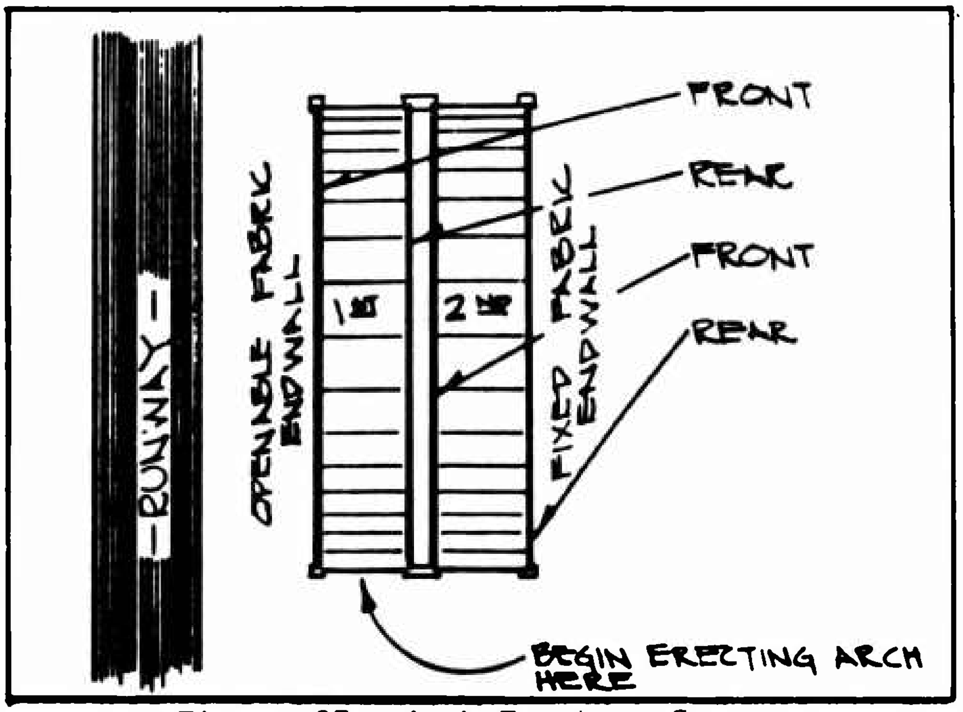


Figure 27. Arch Erection Sequence

1. Openable End Wall Arch

The increased size of the end wall of the ninety (90) foot span hangar (as compared with the fifty-eight (58) foot span hangar) required extensive redesign. Substantial functional improvements have resulted. The greater wind load stresses have been accommodated by strengthening the end arch by the addition of a truss, side columns and a system of radiating cables. This change has further extended the commonality of components by (1) permitting all arch beams to be identical (as opposed to requiring heavier sections on end arches) and (2) by incorporating the personnel doors in the end wall thus eliminating special side wall personnel door units previously substituted for standard panels where required. Improved winching techniques have contributed to more efficient opening and closing of the end wall.

There are three main components in the construction of the arch.

a. <u>"I" Beam Section</u>

The "I" section used for the Main Arch Beam is an Aluminum Association Structural Standard "I" shape 9.900" x 5.750" with a .240" web, alloy 6061-T6. The production tolerances are:

Flatness Deviation: .004 inches per inch of width
Twist: 2.5° per foot of length; 3° maximum
Flange Width: ± 4%
Depth: ± 2.5%, ± .25" minimum

A thorough structural analysis of this "I" - section was programmed and run on a computer in accordance with the loading combinations possible on the structure. SEE APPENDIX A - for coverage.

b. <u>Hinges</u>

The increased size of the main arch beam and overall loading required a heavier hinge than the ones used in the fifty-eight (58) foot span hangar.

The new design was a machined hinge (Fig. 28) cut from 7075-T6 aluminum. A complete hinge consists of a four (4) knuckle half and a three (3) knuckle half.

A hinge test was performed primarily to investigate the failure mode and operating limits of the hinge assembly. (Complete test in Appendixes C and D). The first test assembly was loaded to P = 37,470 pounds where failure occurred. The failure was due to complete shearing of the four (4) 1/2" bolts holding the tension hinge. High strength bolts were substituted for the original hinge bolts. Also the testing configuration was changed. The assembly was then loaded to 75,000 pounds where failure occurred due to the twisting of the beam. (Fig. 29)

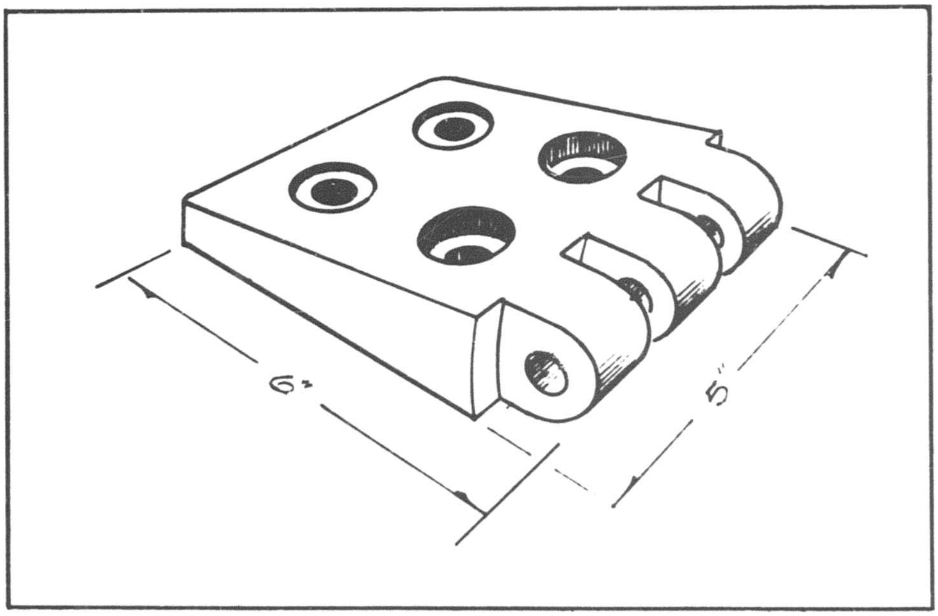


Figure 28. Hinge Half

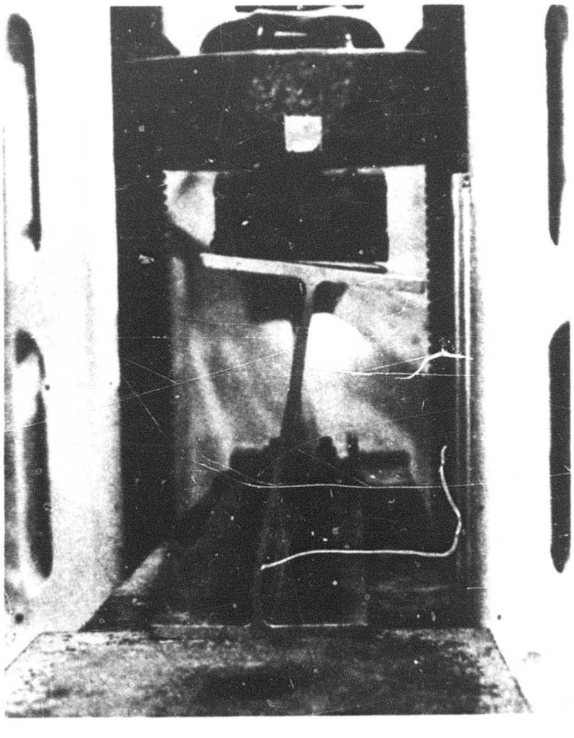


Figure 29. Testing of Main Arch Beam

c. Panels

The major exterior surface of the two (2) arch, ninety (90) foot span hangar consists of aluminum faced sandwich panels. Thirty (30) paper honeycomb core panels and twenty-six (26) polystyrene foam core panels were contained in the two (2) arch prototype. Both core materials were initially developed for the fifty-eight (58) foot span hangar. Except for the addition of an attached aluminum angle along the four foot edges of the 4' x 8' panels (to receive a new kind of arch beam flashing), they were identical in design to the fifty-eight (58) foot arch hangar panels.

Extensive testing on both honeycomb core and foam core panels has been conducted. Based on these tests, the performance of the two types is comparable. At this time the honeycomb core panel is favored largely due to an approximate seven pound weight differential, better heat resistance, and greater impact strength.

In erecting the openable end wall arch, it is essential that the main arch beams and the panels be assembled in the order shown in (Fig. 30) so that the hinges on the beams interlock and the panel flashing overlaps properly to ensure weather proofing.

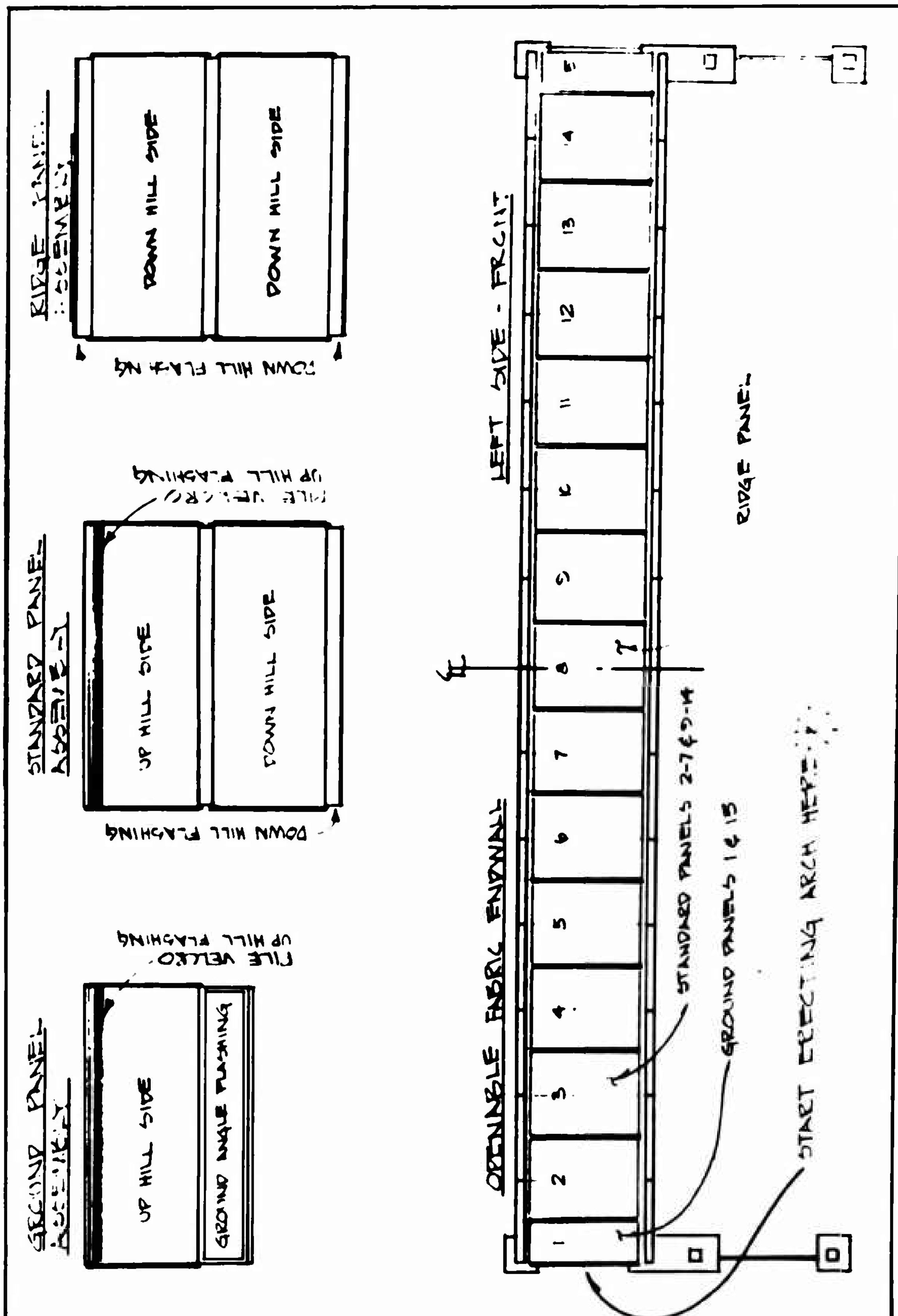


Figure 30. Panel Details and Panel to Beam Relationship

The first step in erection is to attach two clevis adapters to a pair of main arch beams and attach the adapters to the base pad clevises with hand knobs and bolts. (Fig. 31) The ground panel assembly is then camlocked to the beams (Fig. 32).

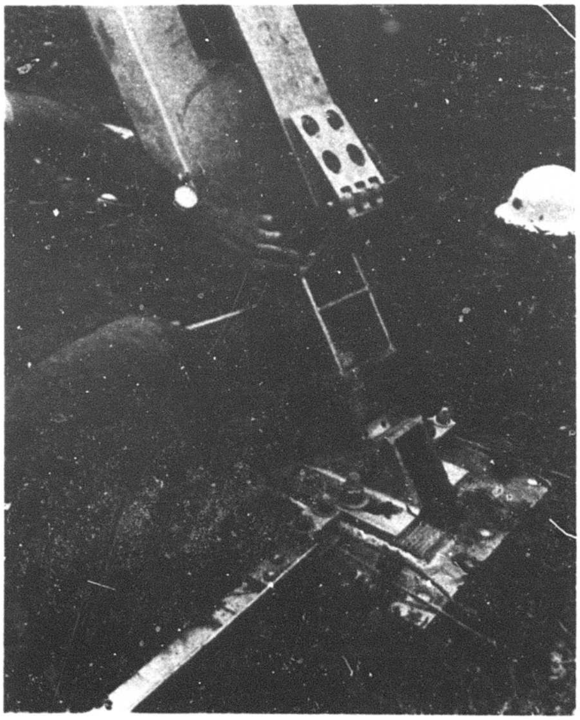


Figure 31. Attachment of Main Arch Beam to Base Pad

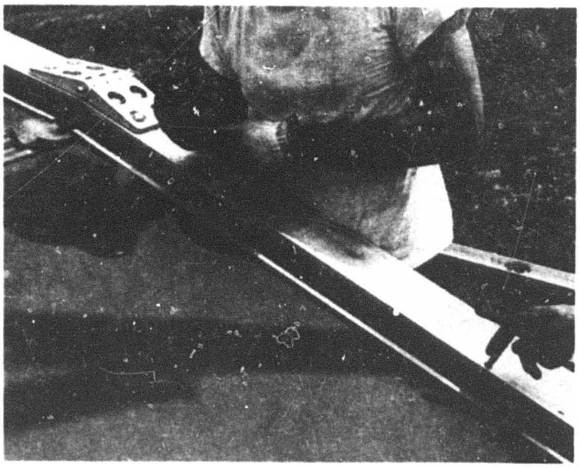


Figure 32. Cam Locking Panels to Main Arch Beams

The next pair of main arch beams are attached by pinning the top hinges. The first double panel assembly is camlocked to these beams. (Fig. 33)

The beams are raised by hand until the bottom hinges engage and are pinned.

As each panel assembly is attached, engage the flashing as shown in (Fig. 34, 35, and 36).

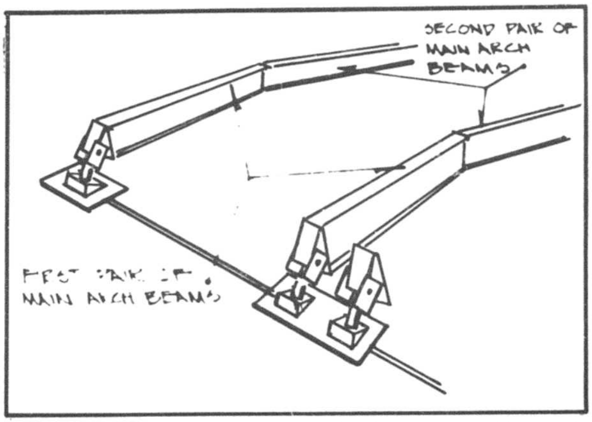


Figure 33. Base Pads and First and Second Main Arch Beams

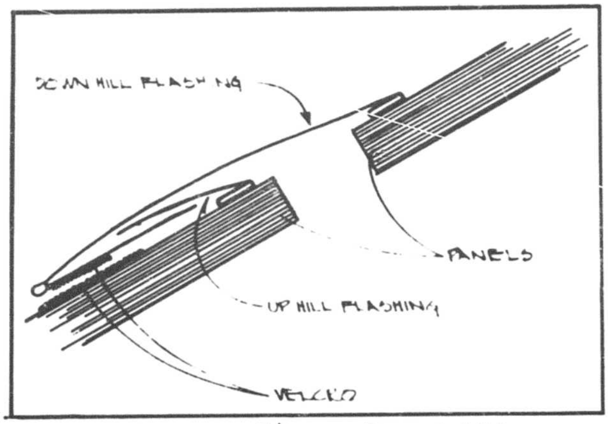


Figure 34. Downhill Panel Flashing

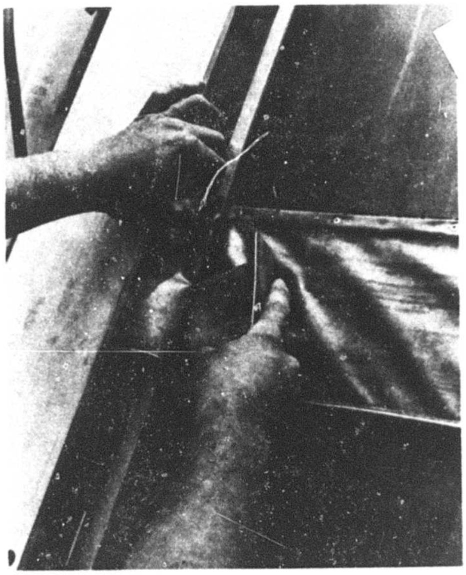


Figure 35. Use of Flashing Tool

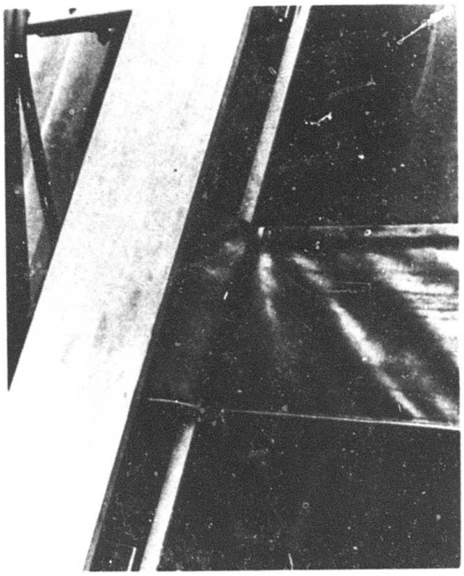


Figure 36. Standard Panels Flashed Before Attachment of "Quick Edge"

When the arch becomes too heavy to lift by hand (depending on manpower available) use the erection gantry, chain hoists and clamps to lift the arch assembly. (Fig. 37)

Figure 37. Lifting the Arch

At this point it is necessary to start attaching the lower arch beams, diagonal trusses, V-trusses, columns and openable end wall.

The lower arch adapter is located on the front, second main arch beam. The position on the beam is determined by the use of the large locating device in the tool box. This places the edge of the adapter link a set distance from the second and third front main arch beam hinge pin. See (Fig. 38)

The first two lower arch beams are attached to the adapter link in the normal beam joinery method, mating the hinges and fixing these with pins. (Fig. 39)

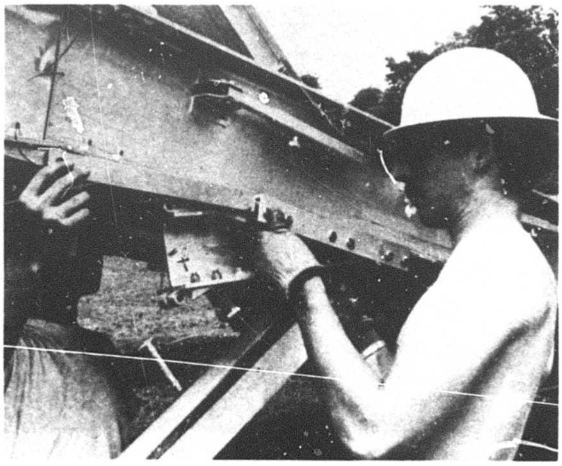


Figure 38. Locating Lower Arch Adapter

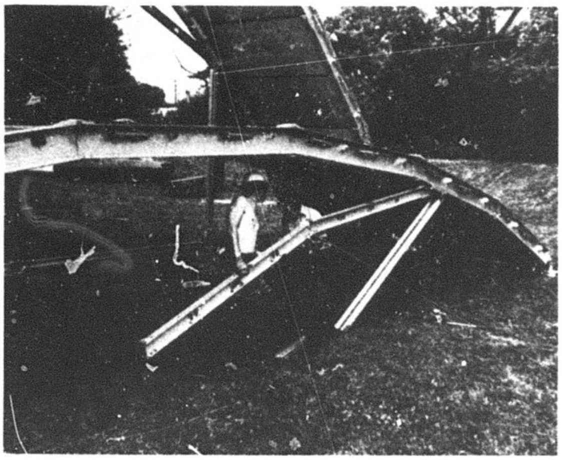


Figure 39. Attachment of Lower Arch

The "I" beam section used for the lower arch beam is an Aluminum Association Structural Standard "I" shape, 5" x 3.5" with a 1.19" web. The alloy is 6061-T6.

The first right-hand openable end wall "V" truss is attached to the second lower arch beam by inserting the truss joint into the upper flange of the lower arch beam as in (Fig. 40). Two pins fix the truss to the beam web. At the top of the "V" truss, the beam clamps are located in their proper positions by means of a small locating device that measures a set distance from the beam hinge pin to the clamp. See (Fig. 41)

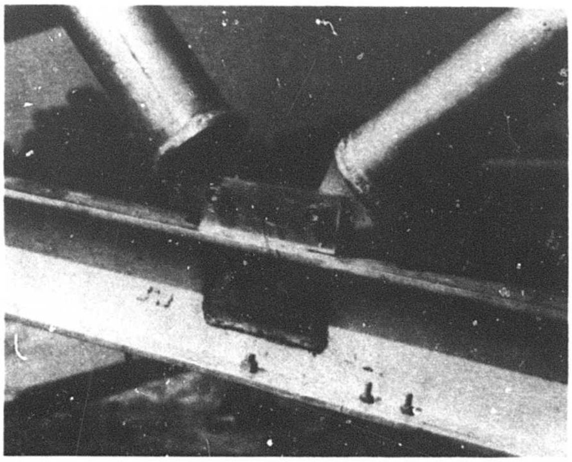


Figure 40. Attachment of "V" Truss to Lower Arch

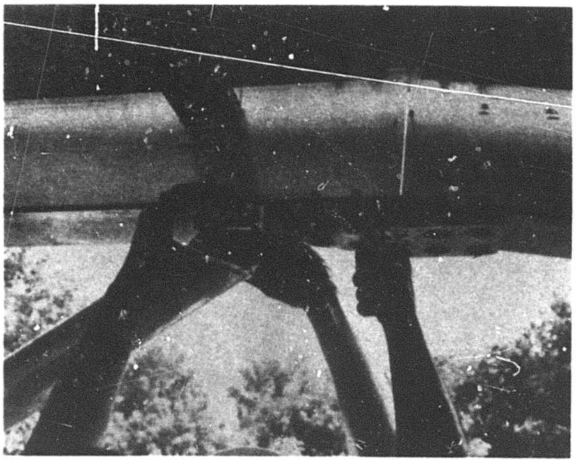


Figure 41. Locating "V" Truss Clamp on Main Arch Beam

At this point in the arch erection sequence, the come-along assemblies are attached to aid in the erection of the lower arch beam. This assembly consists of a ratchet hoist, two cable assemblies and two beam or lifting clamps. See (Fig. 42) There are three (3) come-along assemblies supplied with this hangar. Two come-alongs are used simultaneously, one on the rear main arch beams of the openable end wall arch and one on the front main arch beams.

When erecting the hangar on hard ground conditions the free end of the arch will not dig in. A second come-along must be used on the inside main arch beams. They are used in a walking type operation preventing excessive "kick-out" and eliminating any twisting of the arch segment.

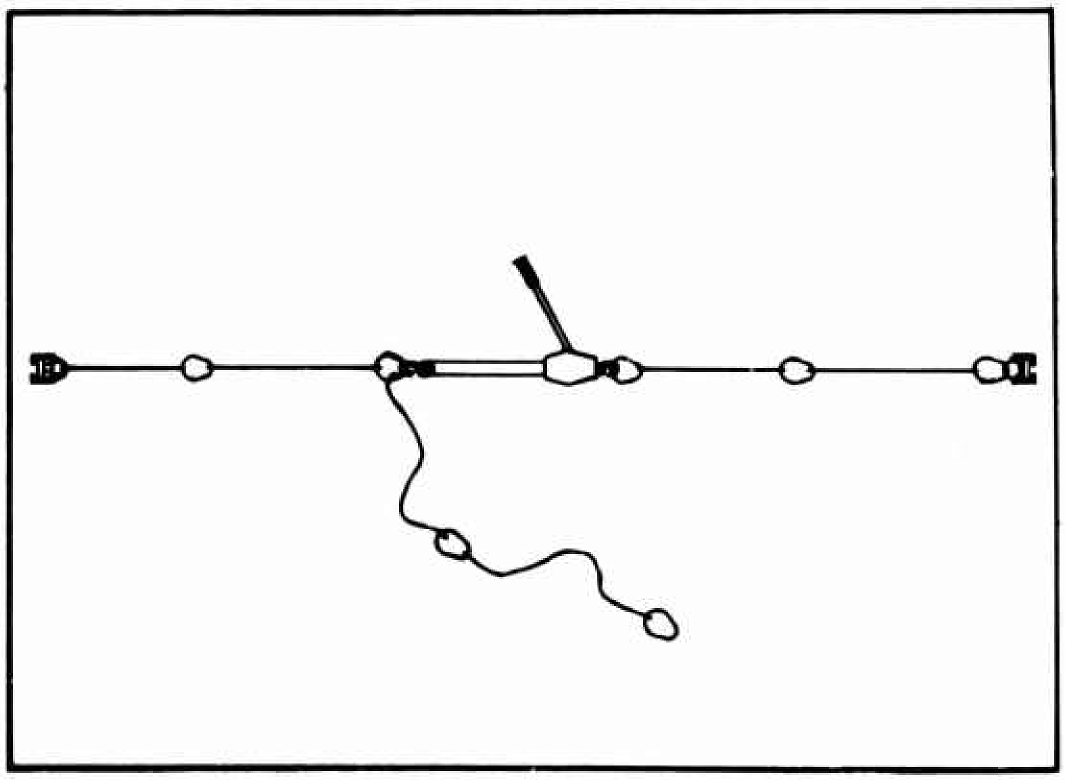


Figure 42. Come-along and Cable Assembly

Diagonal trusses must be added at this point. These trusses are adjustable and are located as in (Fig. 43, 44 and 45).

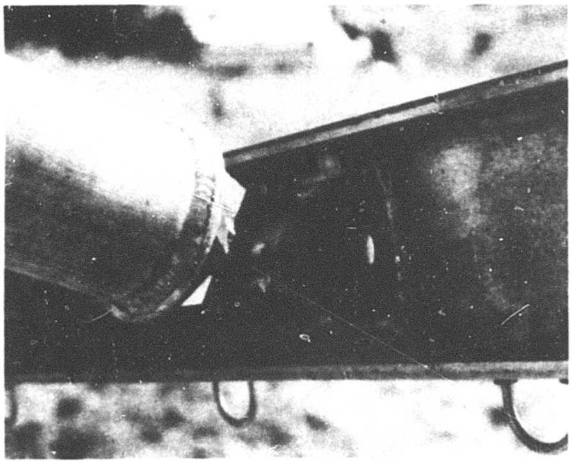


Figure 43. Attachment of Diagonal Truss to Lower Arch Beam

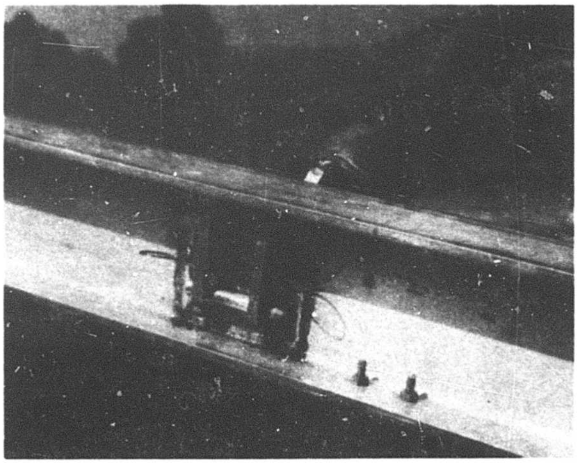


Figure 44. Attachment Detail Lower Arch Beam

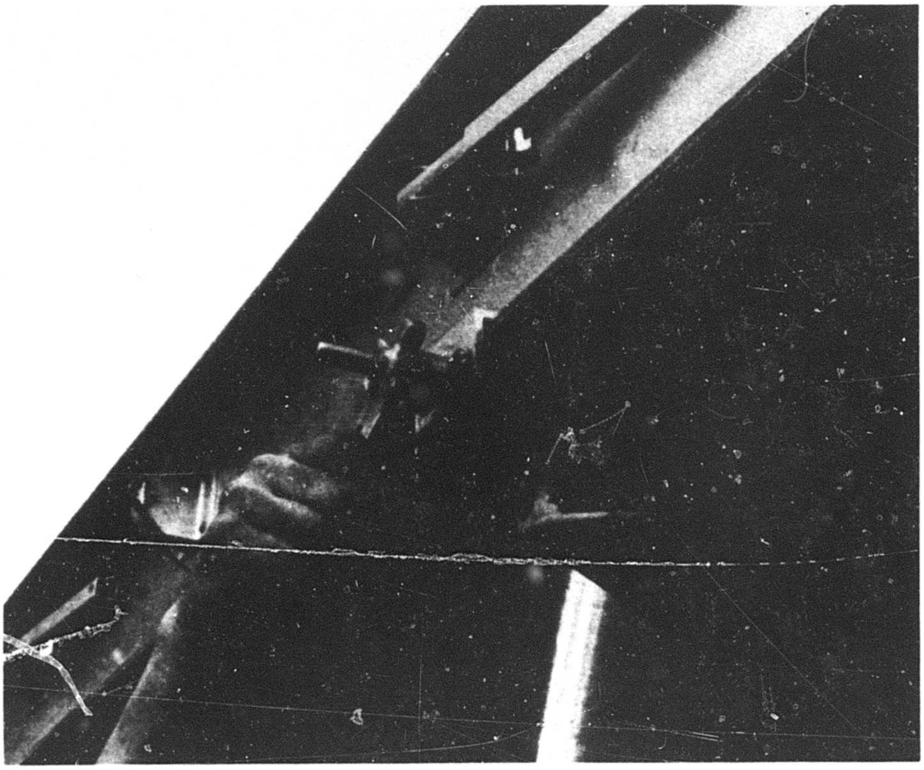


Figure 45. Joint of Diagonal Truss to Main Arch Beam

In addition to adding more lower arch beams and trusses, the lifting pulleys are also located. There are six primary lifting pulleys (Fig. 46) which are attached at fixed positions on the front arch of the openable end wall arch. (Fig. 47)

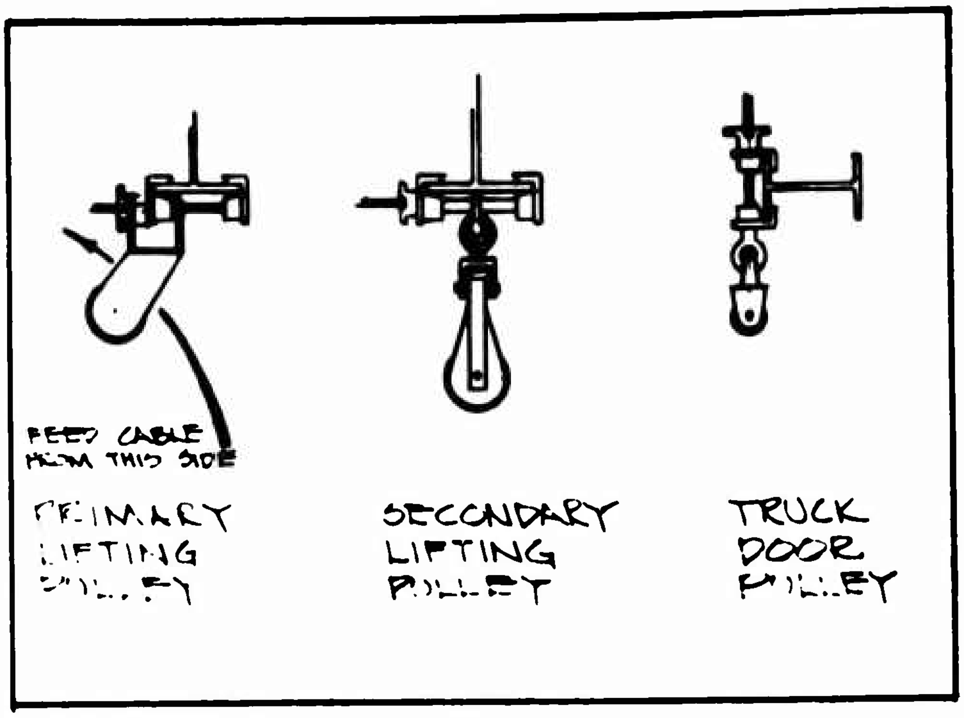


Figure 46. Lifting Pulleys

Figure 47. Primary Lifting Pulley

At this point in the erection sequence, the openable fabric end wall is laid out (Fig. 48). The fabric for the openable and fixed fabric end walls is a special mill run made by Reeves Brothers. It is eighteen (18) ounces per square yard neoprene-coated nylon with an aluminum coating on one side. The material is designated "Coverlight #15540, AL/OD, 60", MIL-C-20696A, Type 2, Class 2". It was chosen from a variety of candidate materials for its strength and durability. The special coating was applied to one side to inhibit the heat transfer properties of the end walls and to provide an interior which could be more easily lighted to a comfortable work level.

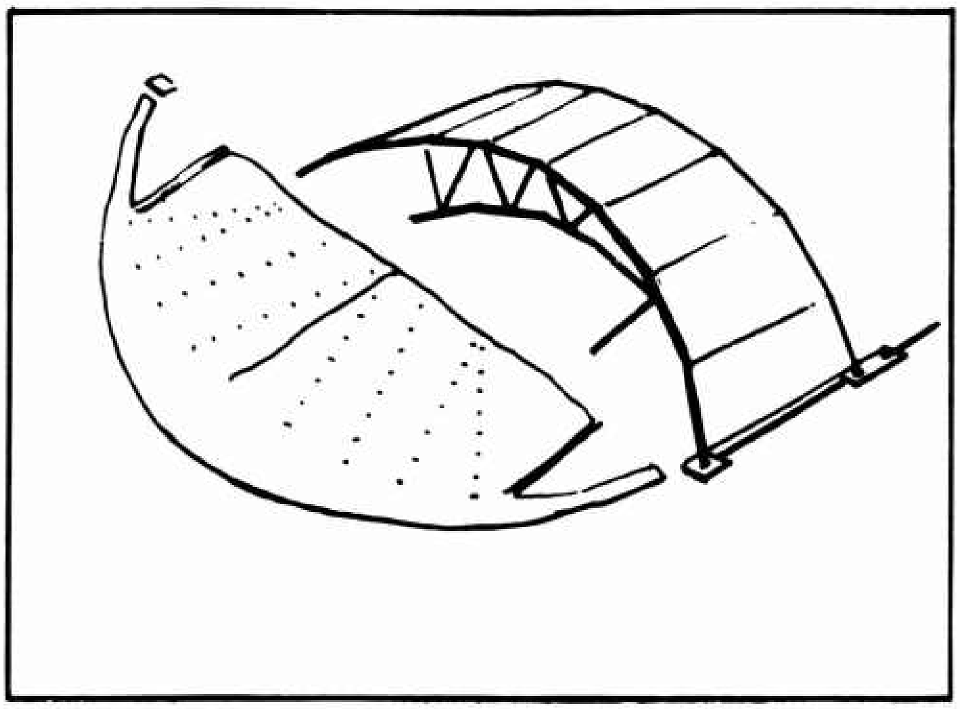


Figure 48. Openable Fabric End Wall Layout Prior to Erection

The radial and lifting cables must be laid out to determine the length and identify each one (Fig. 49). The cables are 1/4" stainless steel wire rope, with clevis fittings at one end to be attached to the lower arch beam. The other end has a length of chain for adjustment at the ground beam. (Fig. 50)

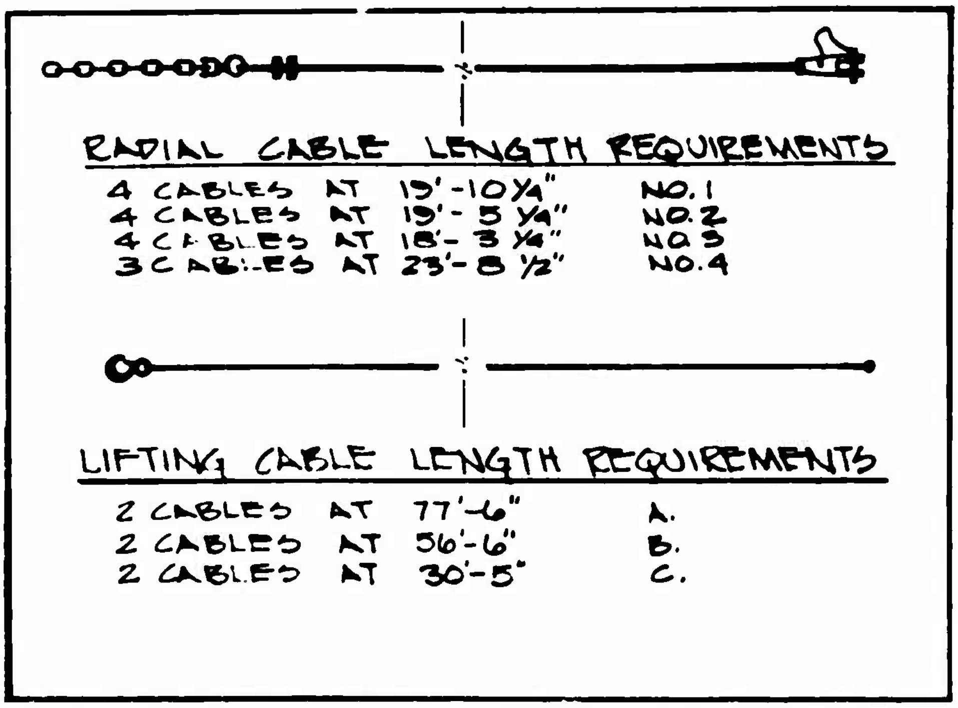


Figure 49. Radial and Lifting Cable Schedule

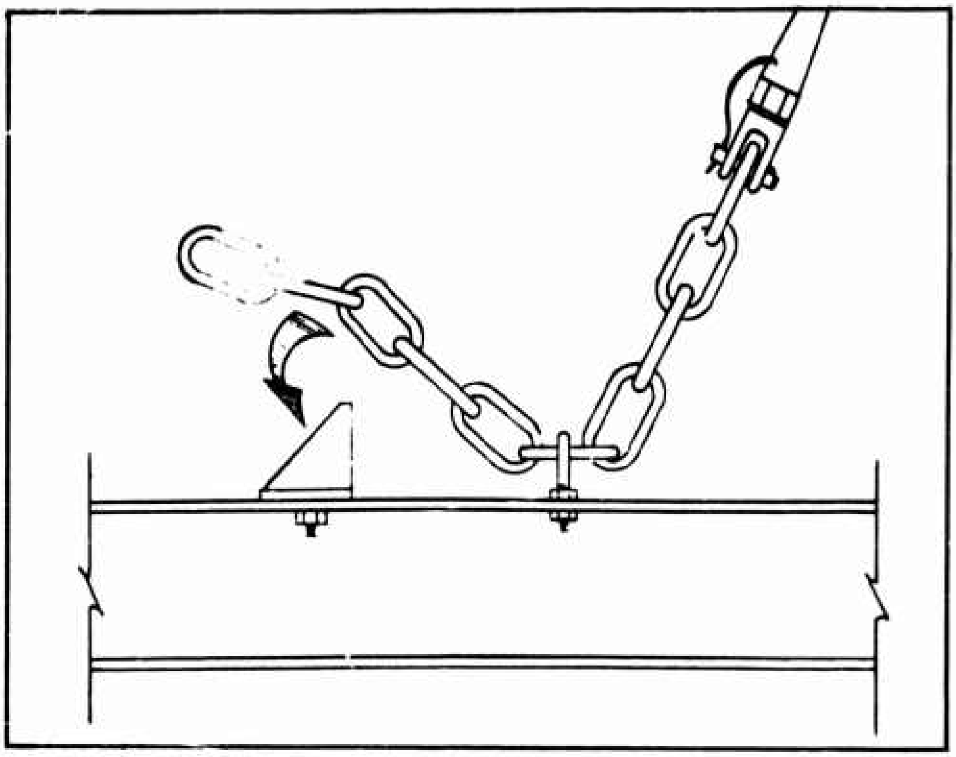


Figure 50. Radial Cable Chain Latch

The radial or load distributing cables are used to transfer the wind loads from the fabric to the arch structure. (Fig. 51) There are eight (8) radial cables on the openable end wall and seven (7) radial cables on the fixed end wall. The radial cables are:

Sizes	Length
#1	20.25'
2	19.75'
3	18.958'
4	24.485'

Structural Analysis is in Appendix D

The radial cables run through "D" rings attached to the end wall. They are threaded before the end wall is attached.

Six lifting cables are needed for the openable end wall.

Quantity	Length
2	77'-6"
2	56'-6"
2	30'-5"

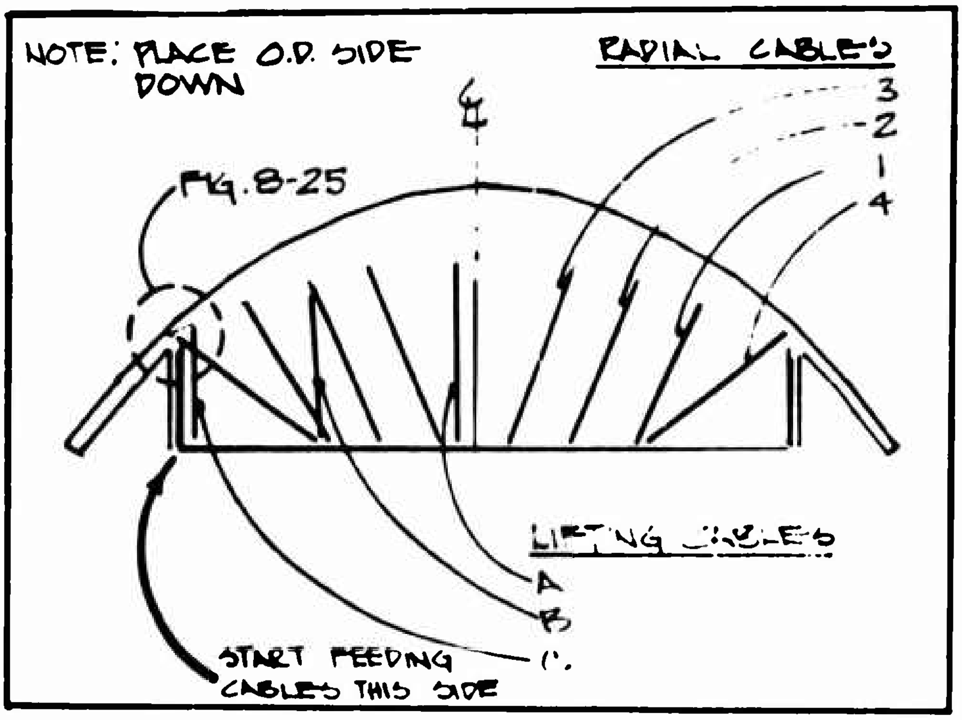


Figure 51. Radial and Lifting Cable Placement

A lifting cable consists of 1/4" nylon coated wire rope with a 5" snap hook at one end which attaches to the openable end wall ground beam. The cable is threaded through a series of "D" rings on the fabric, and through a series of pulleys on the arch to a lifting winch.

At this point in the erection procedure, the attachment of the snap hooks to the "U"-bolts on the lower arch beam begins. For configuration see (Fig. 52). The radial cable clevises are attached to their respective large "U"-bolts on the adapter link and on the lower arch beams. (Fig. 53)

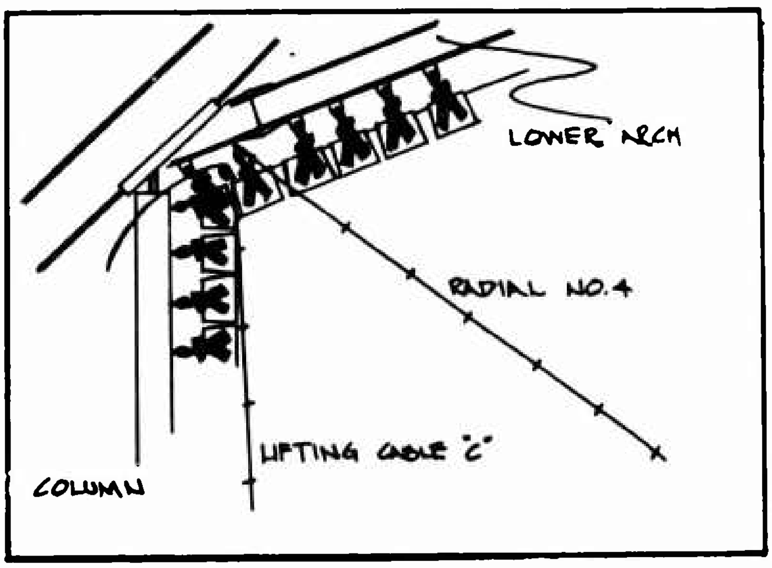


Figure 52. Attachment of End Wall to Lower Arch Beam

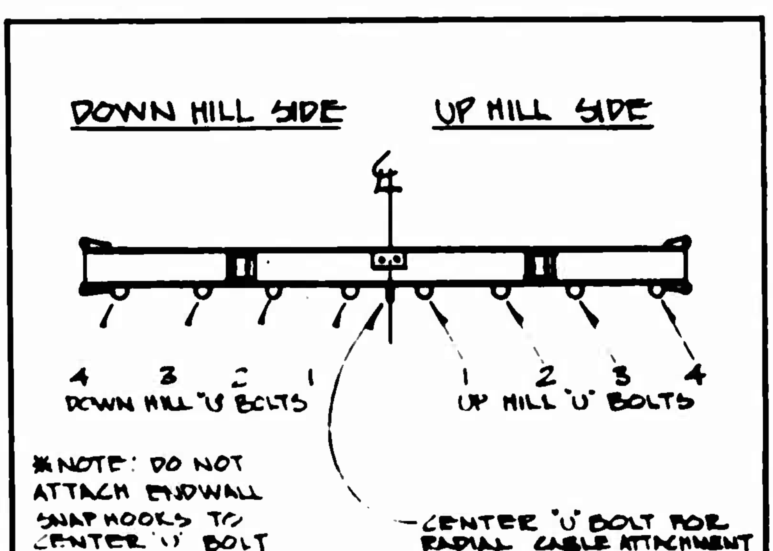


Figure 53. Lower Arch Beam Detail

To flash the large gap between the lower arch beam and the main arch beam (Fig. 54) an upper fabric panel, which is part of the openable end wall fabric, is raised over the main arch beam and is attached to the panel assemblies (Fig. 55). The attachment is made with the mating of a vinyl extrusion, referred to hereafter as "quick-edge", and an aluminum angle which borders the panel assemblies. The "quick-edge" extrusion is attached by hand to the aluminum extrusions to form a very efficient weather-proof seal. (Fig. 56)

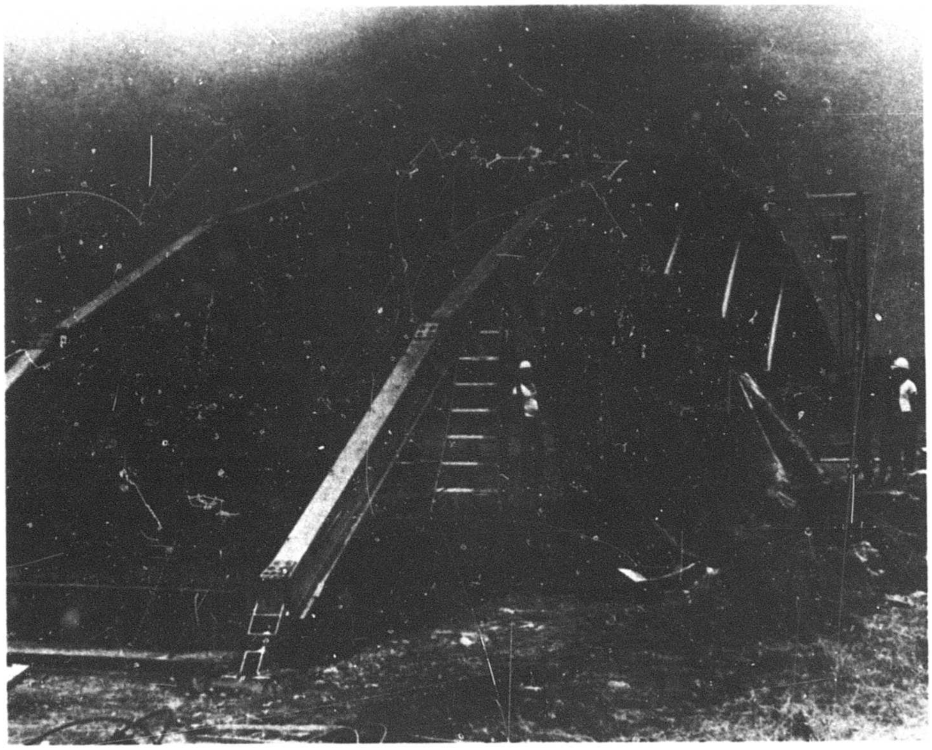


Figure 54. Attachment of End Wall

Figure 55. Attachment of Upper Fabric Panel

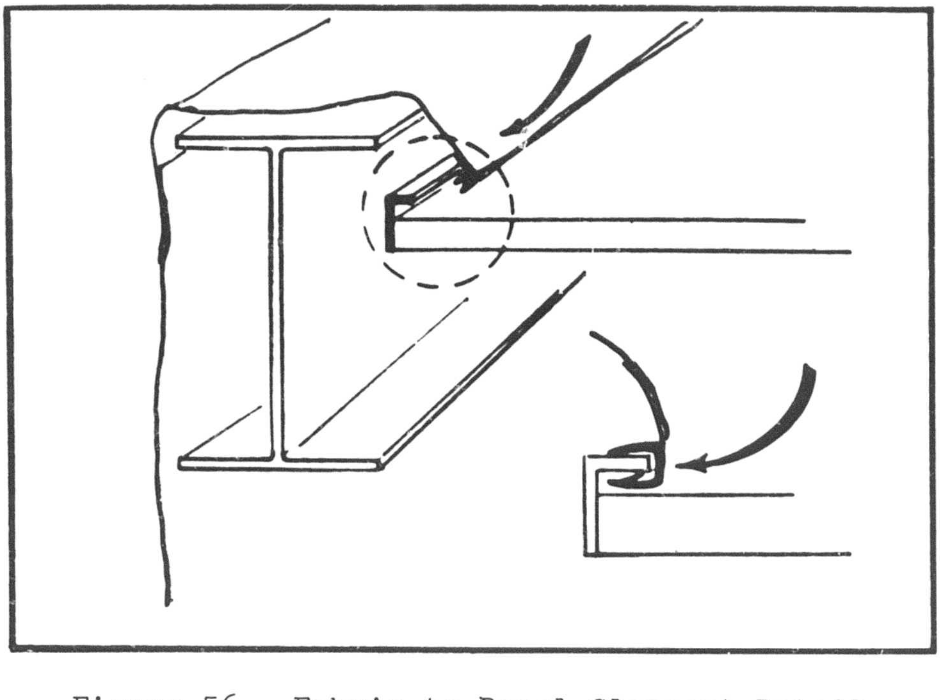


Figure 56. Fabric to Panel Closeout Detail

After seven (7) panel assemblies have been erected a special ridge panel must be attached. This panel has down-hill flashings on both sides (Fig. 57). At this point approximately half of the shelter is erected.

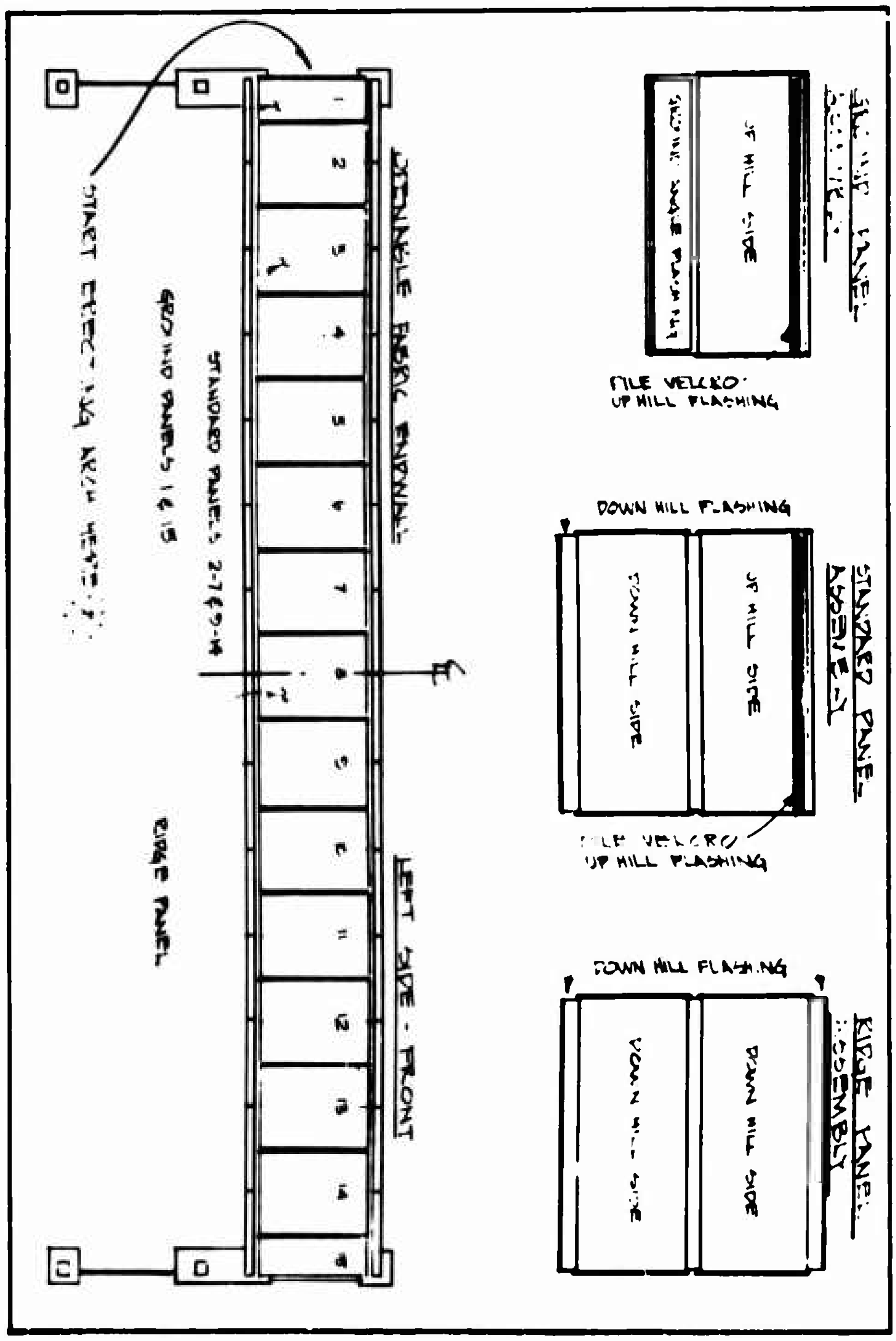


Figure 57. Panel Details and Panel to Beam Relationship

The attachment of main arch beams, panel assemblies, end wall fabric, cables, lower arch beams and truss assemblies continues until the twelfth pair of main arch beams has been reached. The adaptor link for the lower arch beam is attached to main arch beam thirteen. The last main arch beam pair is attached and the complete arch is ready to be attached to the base pad clevis. With the help of the erection gantry and the come-alongs, the clevis adapter is positioned into place and the bolt and hand knob are attached (Fig. 58).

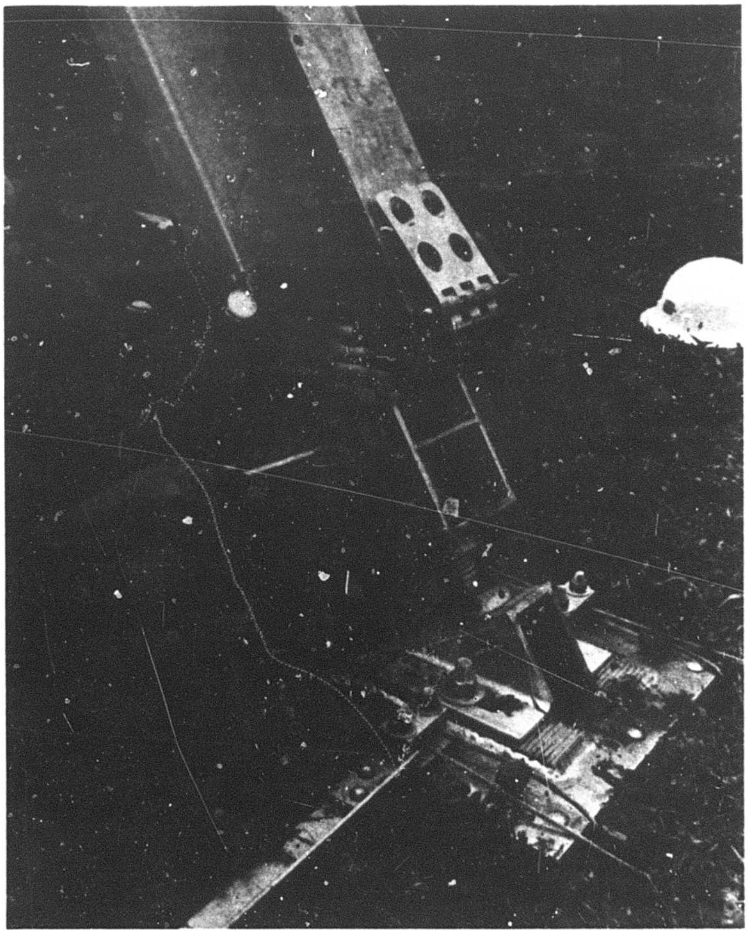


Figure 58. Securing Arch to Corner Base Pad

To complete the arch erection, the ground panel flashing is attached to the ground angles at both ends of the openable end wall arch. (Fig. 59)

2. The Fixed End Wall Arch

Erection of the fixed end wall arch is similar except for the addition of a truck door and its supporting members. Only seven radial cables are used, and the lifting cables and pulleys are eliminated.

As the ninth lower arch beam is attached, the truck door column is clamped into place.

The remaining part of the fixed end wall arch is erected in the same manner as the openable end wall arch.

Arch Beam Spacer primary functions:

1. They establish a structural tie between arches and in doing so, make possible the accommodation of minor variations of terrain.

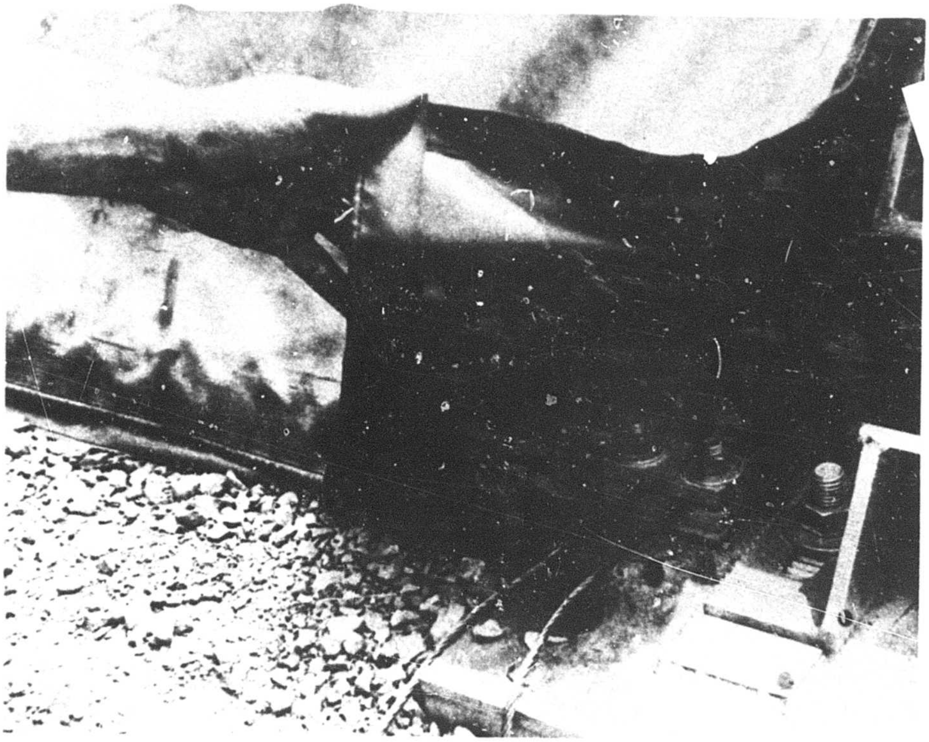


Figure 59. Attachment of Ground Panel Flashing to Ground Angle

2. They serve as a ladder for access to the upper portions of the hangar shell.

When the two (2) arches are erected they are locked together by swinging the spacer bars out from beam webs loosening the hand knobs and sliding the spacers out to the right length, and pinning them to the corresponding fittings on the adjacent beams (Fig. 60). The hand knob is tightened with a tool provided in the tool kit.

F. PERSONNEL DOORS

Four personnel doors are used in the ninety (90) foot span hangar, two in each end wall.

The first step in the erection of a personnel door is the placing of the column base pads under the suspended upper portion of the personnel door columns. (Fig. 61)

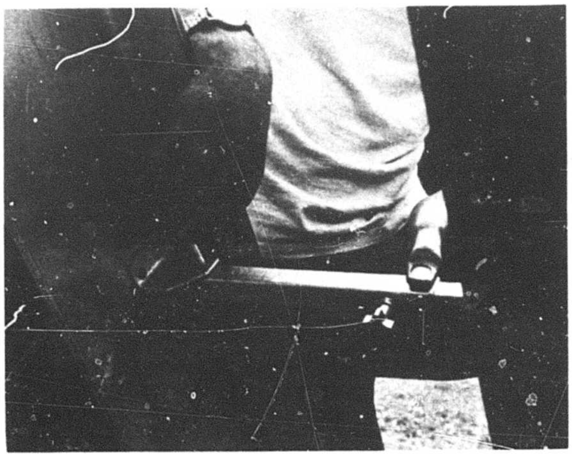


Figure 60. Attachment of Spacer Between Front and Rear Arches

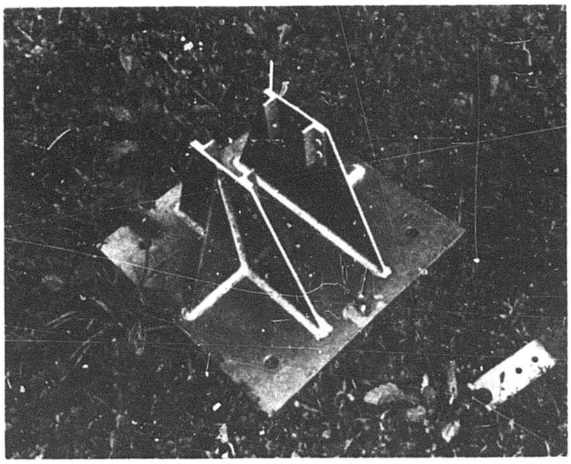


Figure 61. Personnel Door Column Base Pad

The lower "I" section of the column fits into the base pad. (Fig. 62)

The personnel door panel assembly is lifted into place and camlocked to the column. (Fig. 63) Four (4) personnel door panel clamps are attached to the main arch beam and the panel. (Fig. 64)

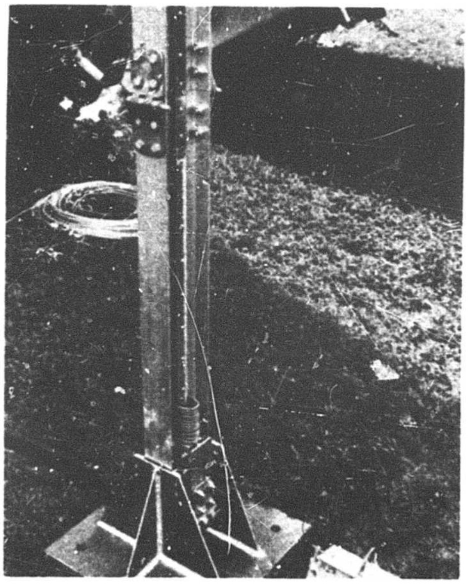


Figure 62. Personnel Door Column Assembly

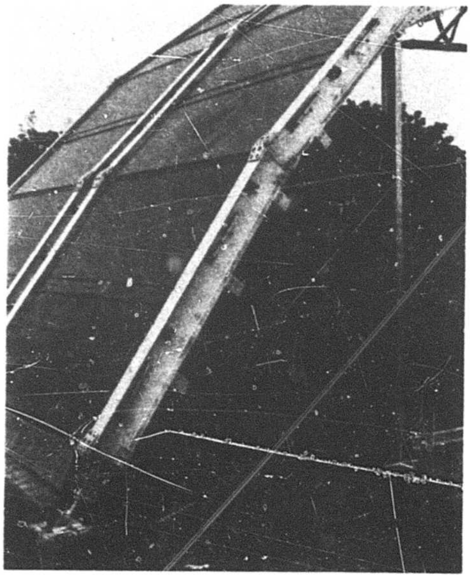


Figure 63. Personnel Door Assembly

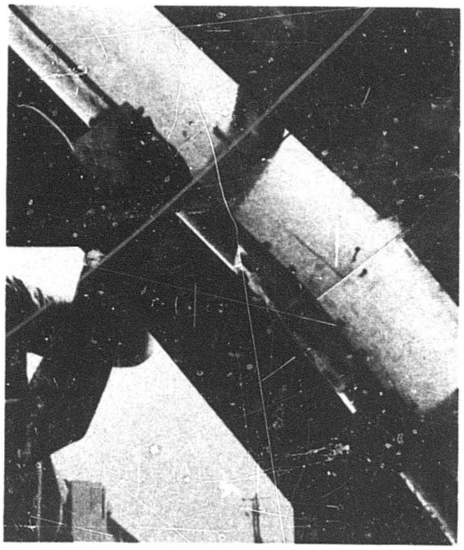


Figure 64. Personnel Door Panel Clamp

Personnel door panel ground angles close out the bottom of the door panel and are attached to the large main arch beam base pad and personnel door column base pads. Fabric flashing from the door panel mates with the angle, using Velcro to weather seal the bottom of the door. (Fig. 65) The rest of the door is weather sealed by taking the fabric flap from the end wall extending across the personnel door panel and attaching it to the door panel by mating "quick-edge" and Velcro strips. (Fig. 66)

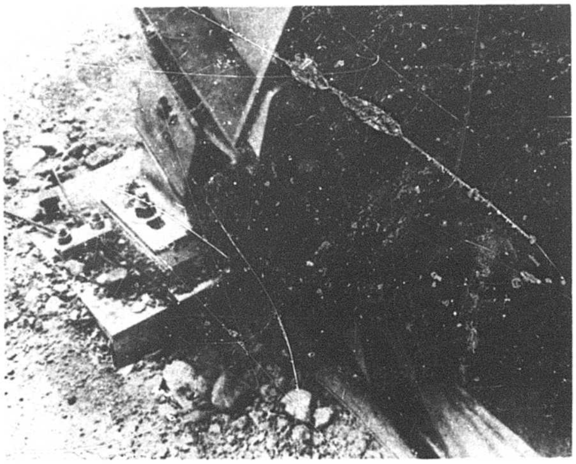


Figure 65. Fabric Flashing at the Bottom of the Door Panel

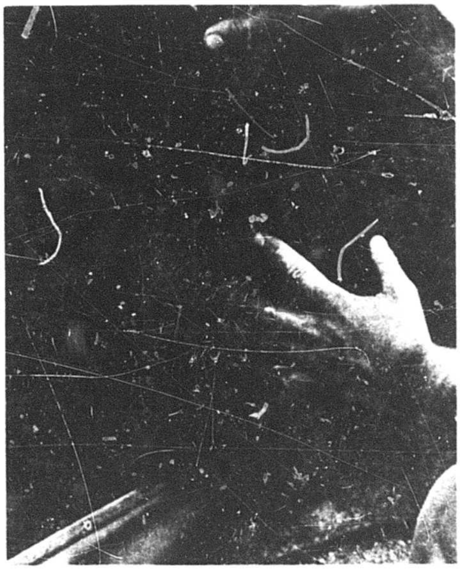


Figure 66. Velcro Weather Seal at the Side of the Door Panel

G. END WALL LIFTING SYSTEM

The Openable End Wall Lifting System is comprised of six (6) primary pulleys, ten (10) secondary pulleys and two (2) three-barrel winch assemblies.

The primary pulleys have been located on the front of the openable end wall arch as the arch was erected.

The secondary pulleys (Fig. 67) are located by climbing the spacer bars and locating the pulley on the main arch beams.

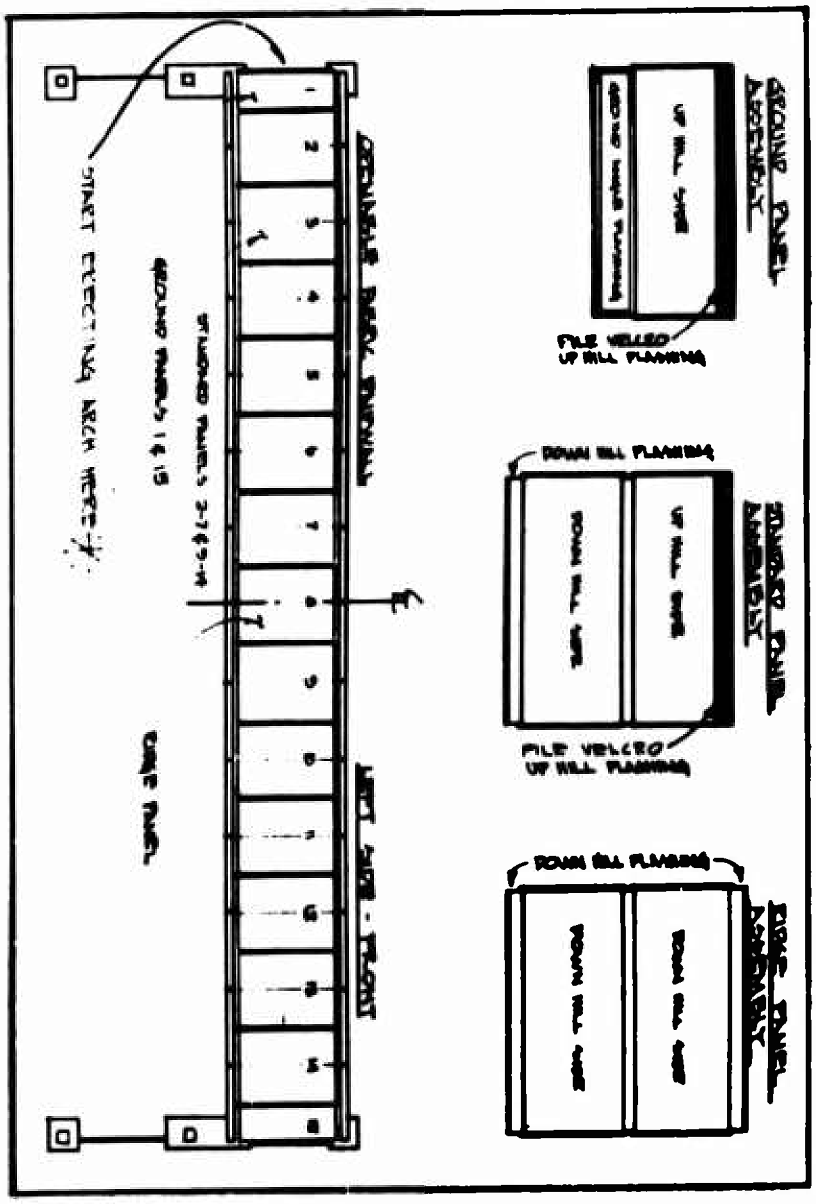


Figure 67. Panel Details and Panel to Beam Relationships

The secondary pulley serves as a guide pulley from the primary pulley to the winch. For an optimum wind of cable on the winch, a good approach angle or "fleet" angle must be provided. If this optimum angle is available, a mechanical reeling mechanism on the winch is not needed. After the erection is completed, these pulleys may be moved in either direction to take up cable slack and to provide this necessary "fleet" angle.

The openable end wall is raised at six (6) points along the ground beams to provide a clear span at maximum opening to conform approximately to the arch configuration and to allow an F-111 aircraft entrance and exit.

To perform this action, two three-barrel winch assemblies are located on the main arch beams, one on each side of the structure approximately 3.5' from the ground (Fig. 68). The cables from the secondary pulleys are fed onto the winches, the shortest cables are attached to the smallest barrels, the longest cables are attached to the largest barrels, and the intermediate length cables are attached to the center barrels. An important principle used in the design of the winch was to limit the wrappings on the winch barrels to one thickness to efficiently control the amount of cable taken up, thus raising the end wall at a predetermined rate. (Fig. 69)

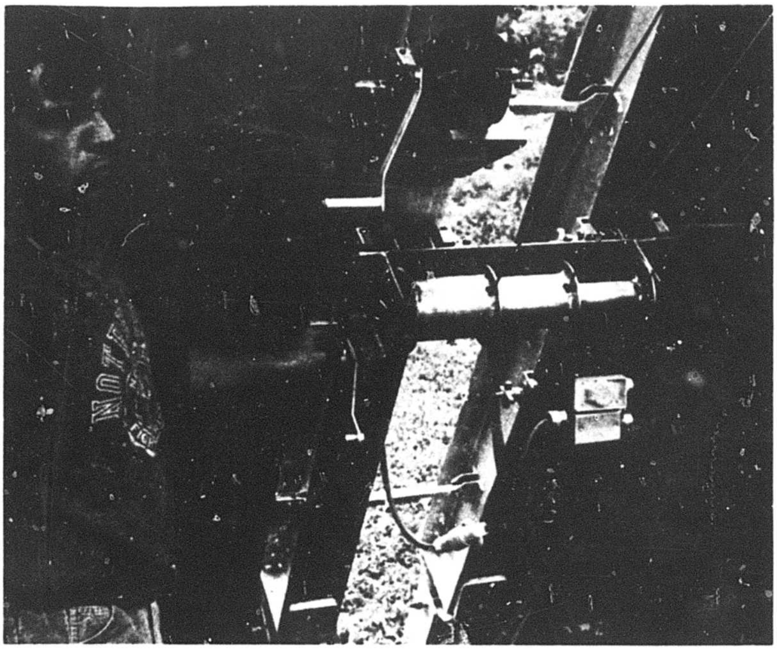


Figure 68. Three-Barrel Winch Assembly

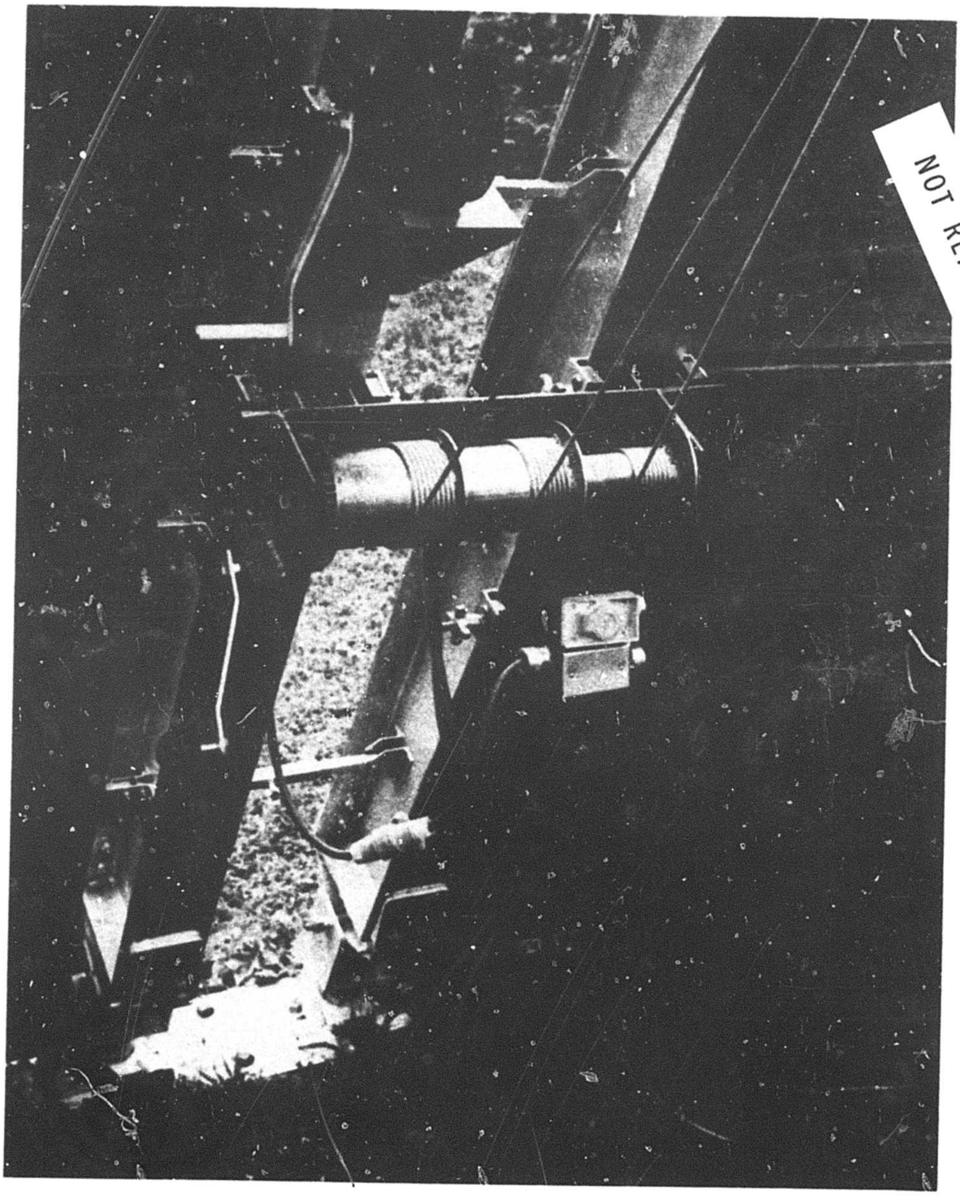


Figure 69. Winch with Cable Wrap

The openable end wall ground beams are laid out in the order depicted in (Fig. 70). These are 3.0" x 4.0" aluminum "I" sections. These beams afford solid lifting and lockdown members for attaching the end wall fabric. Two rows of snap hooks on the fabric are snapped on to "U" bolts on the beams, the first row snapped directly to the "U" bolts, the second row wrapping around the beam to form a ground skirt enclosing the ground beam "I" section. (Fig. 71) The large 5" snaphooks on the lifting cables are attached to the large "U" bolts.

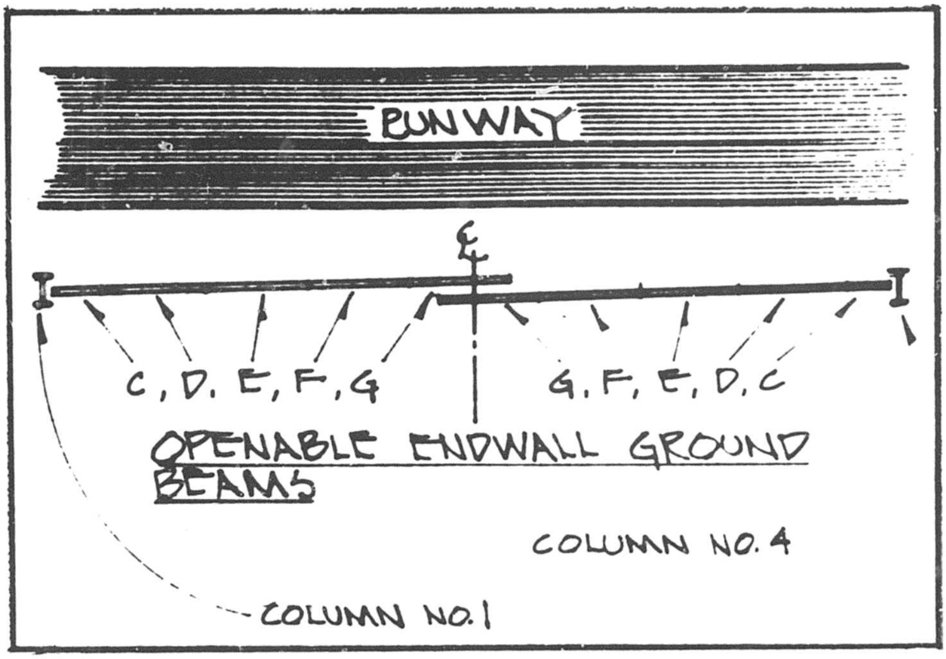


Figure 70. Openable End Wall Ground Beam Layout

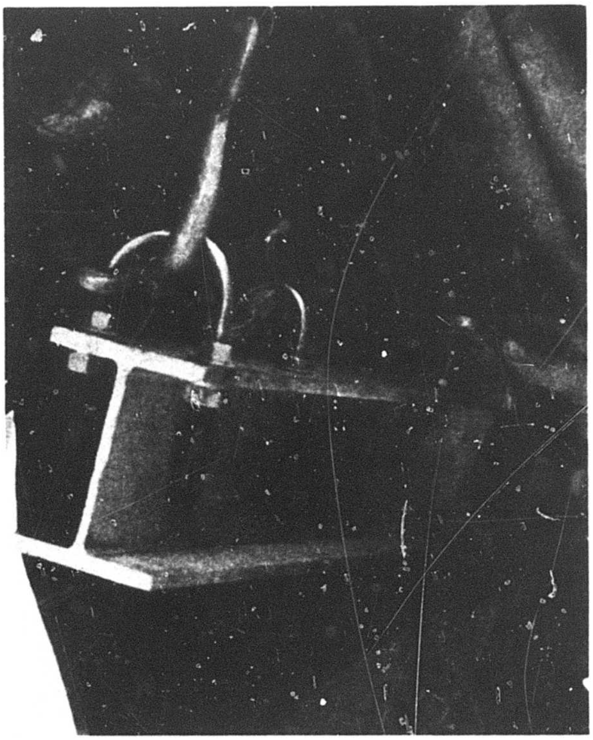


Figure 71. Openable End Wall Ground Beam Fabric Attachment

Using both end wall winches, the end wall should be raised about one (1) foot to allow the base pad lockdown devices to be placed in the correct position. The ten (10) lockdown devices are placed under the beams and located under the "ears" attached to the beams. The end wall is lowered and the "ears", which are spring-loaded, clamp over the locking plate on the base pad. (Fig. 72). The lockdown device is a pedal operated wedge which rides up between the spring-loaded ears of the end wall ground beam and releases the ground beam assembly for lifting. (Fig. 73)

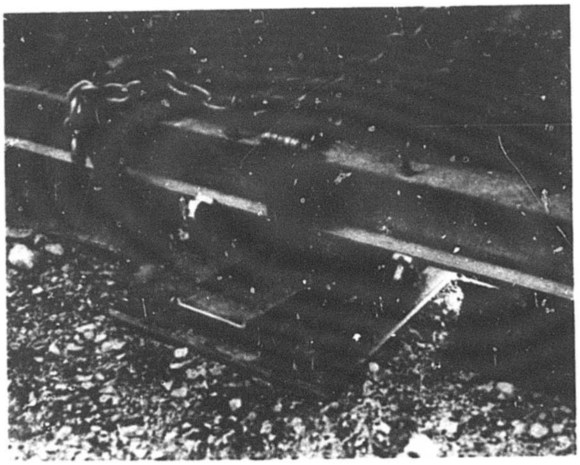


Figure 72. Openable End Wall Ground Beam and Lockdown Base Pad

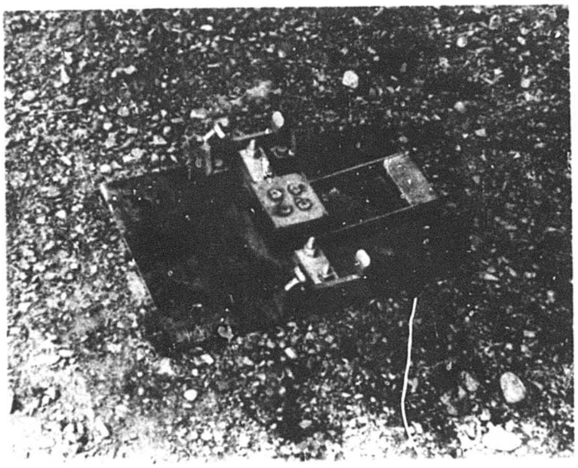


Figure 73. Lockdown Base Pad

H. FIXED FABRIC END WALL ATTACHMENT AND TRUCK DOOR ASSEMBLY

The fixed end wall contains a 12 foot wide by 10 foot high truck door. The frame consists of two columns attached to the lower arch beam during arch erection, a header beam assembly, a movable ground beam assembly, the fabric door and the lifting cable assembly and winch. (Fig. 74)

The truck door header beam assembly is composed of three (3) beams (Fig. 75) attached to the horizontal hinges on the truck and personnel door columns. The horizontal fabric snaphooks of the end wall are attached to the "U" bolts on top of the header beam. The fixed end wall vertical snaphooks attach to the rings on the personnel door column and to the "U" bolts and rings on the truck door column. The snaphooks on the truck door attach to the personnel and truck door columns.

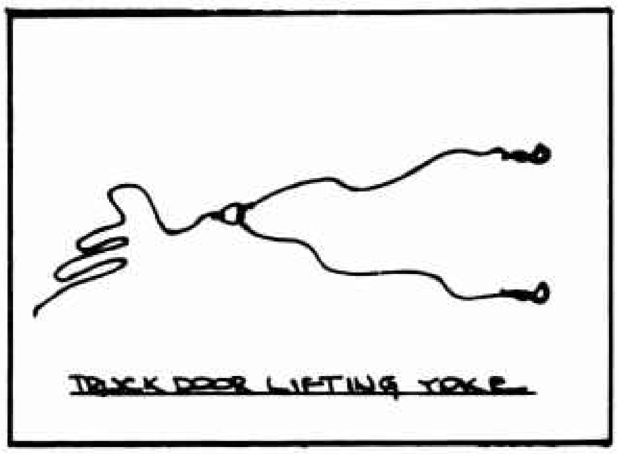


Figure 74. Truck Door Lifting Cable and Yoke

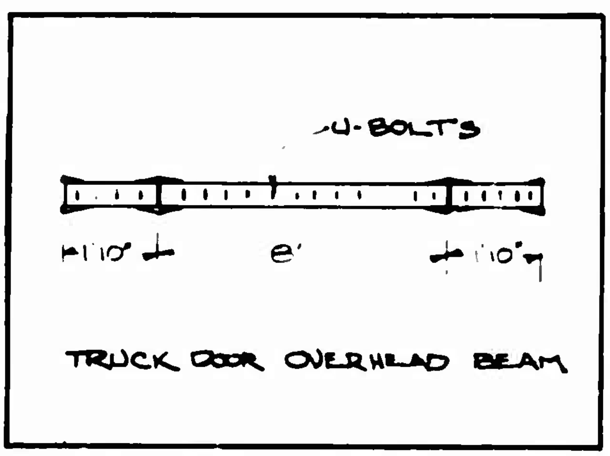


Figure 75. Truck Door Header Beam

The fixed end wall ground beams connect in the order shown in (Fig. 76). The end wall and truck door fabric is attached to the ground beams in the same manner that the openable end wall fabric was attached.

The fixed end wall base pads are clamped to the fixed end wall ground beams at the cut outs in the bottom of the fabric end wall. Due to the fixed nature of the end wall, the base pads have a clamping mechanism. (Fig. 77)

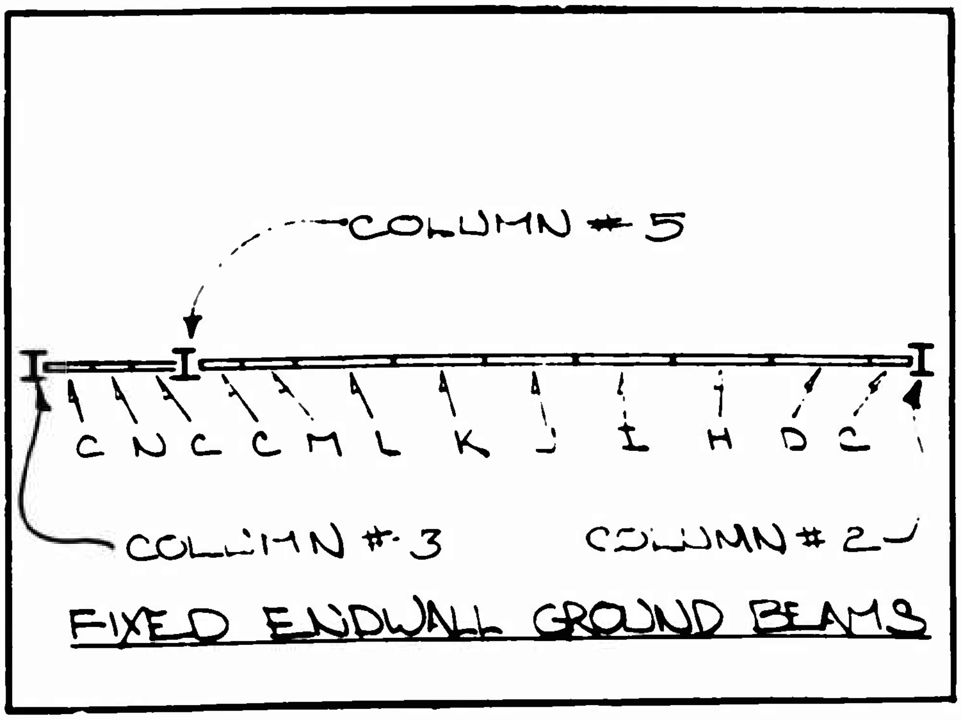


Figure 76. Fixed End Wall Ground Beams

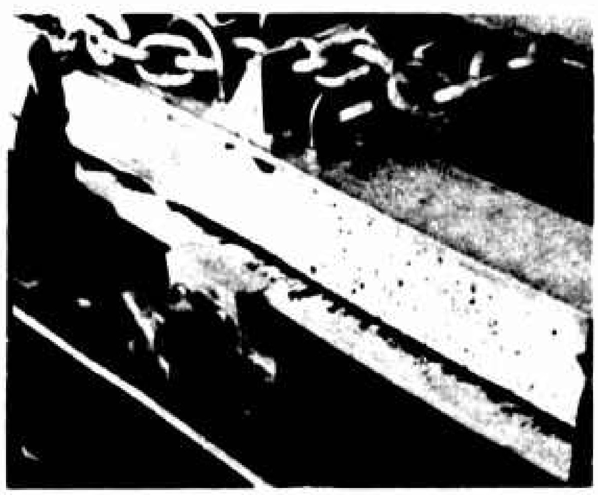


Figure 77. Fixed End Wall Base Pad and Ground Beam

The truck door is raised by the lifting yoke and a small winch. (Fig. 78) The cables are attached to the truck door ground beam, threaded through the "D" rings on the fabric and through the pulleys located on the truck door header beam. (Fig. 79) The single cable from the yoke assembly is fed through the secondary pulley on the rear main arch beam of the openable end wall arch, and down to the winch.

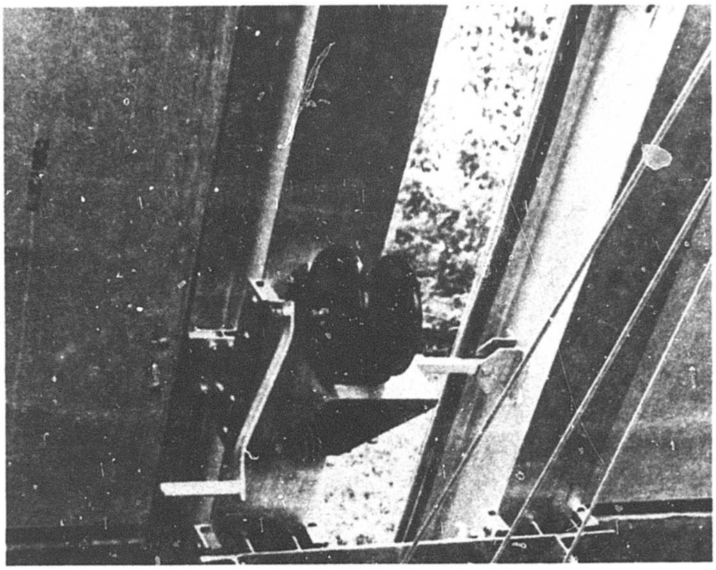


Figure 78. Truck Door Winch

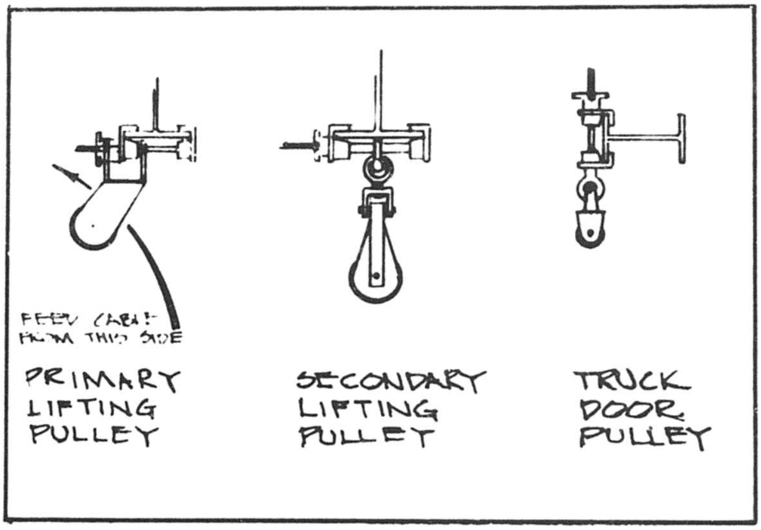


Figure 79. Lifting Pulleys

After attachment of the ground beams and ground beam base pads the end walls are complete except for the column and personnel door flashings. The column flashings are ten (10) foot pieces of fabric covered "Ethafoam" with an aluminum channel on one edge. These flashings are attached to their respective columns with small ball check pins (Fig. 80). The fabric pieces extending down the columns are part of the end wall and are attached to the column and personnel door flashings with "quick-edge" extrusions. (Fig. 81)

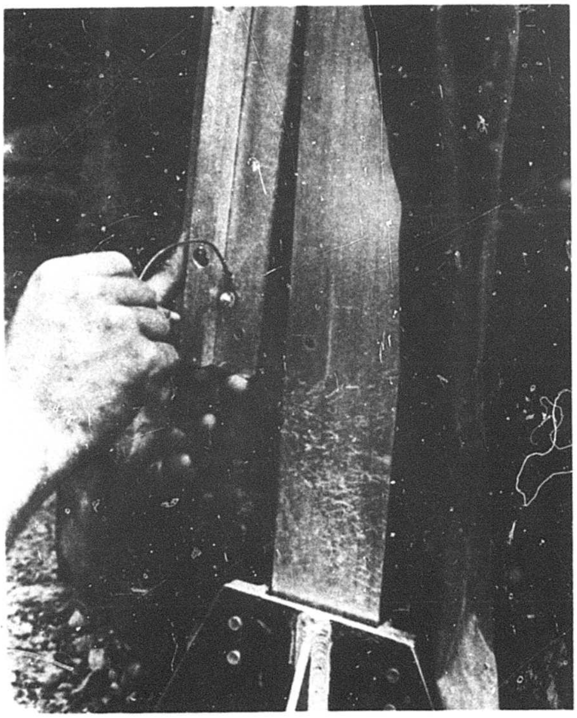


Figure 80. Column Flashing Attachment

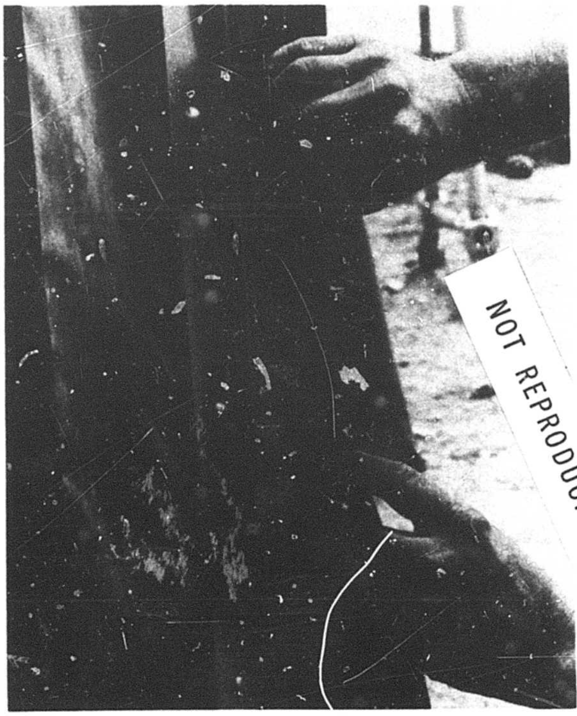


Figure 81. Attachment of End Wall "Quick-Edge" to Column Flashing

I. ELECTRICAL SYSTEM

The electrical system consists of a distribution panel board, two (2) cable assemblies that span the entire structure; one (1) three conductor, one (1) four conductor and two (2) cable assemblies that contain the light fixtures, two (2) fixtures per assembly and two (2) outlet box assemblies.

The outlet box, with two **eight** (8) foot cords is placed on the main arch beam nearest the truck door. (Fig. 82) The female ends of the 105 foot, three and four conductor cable assemblies are carried over the entire structure to mate with the corresponding male receptacles of the second outlet box assembly. (Fig. 83) The male ends of the same 105 foot cables and the male ends of the outlet box assembly (four male ends) are plugged into the electrical panel box. The two conductor cables of the light fixtures are plugged into the remaining cable of the outlet box assemblies. The junction box is attached to the twelfth spacer and the short light fixture cable hangs from this point. The other cable is extended up the arch and hangs from the twenty-second spacer.

J. TOOL BOX

The tool box provided with the shelter serves two purposes: (1) storage for all of the small tools needed during erection and (2) an electrical junction box. The tool locations are called out in detail in (Fig. 84)

Figure 82. Outlet Box with Eight (8) Foot Leads

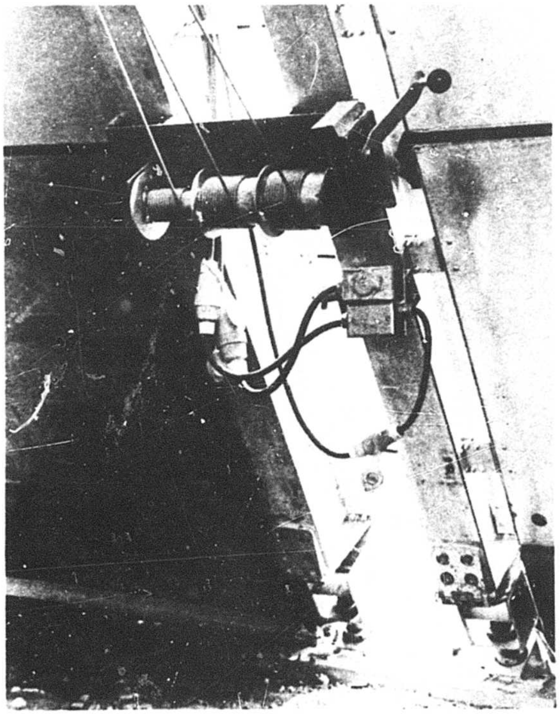


Figure 83. Outlet Box and Connection of One Hundred and Five (105) Foot Leads

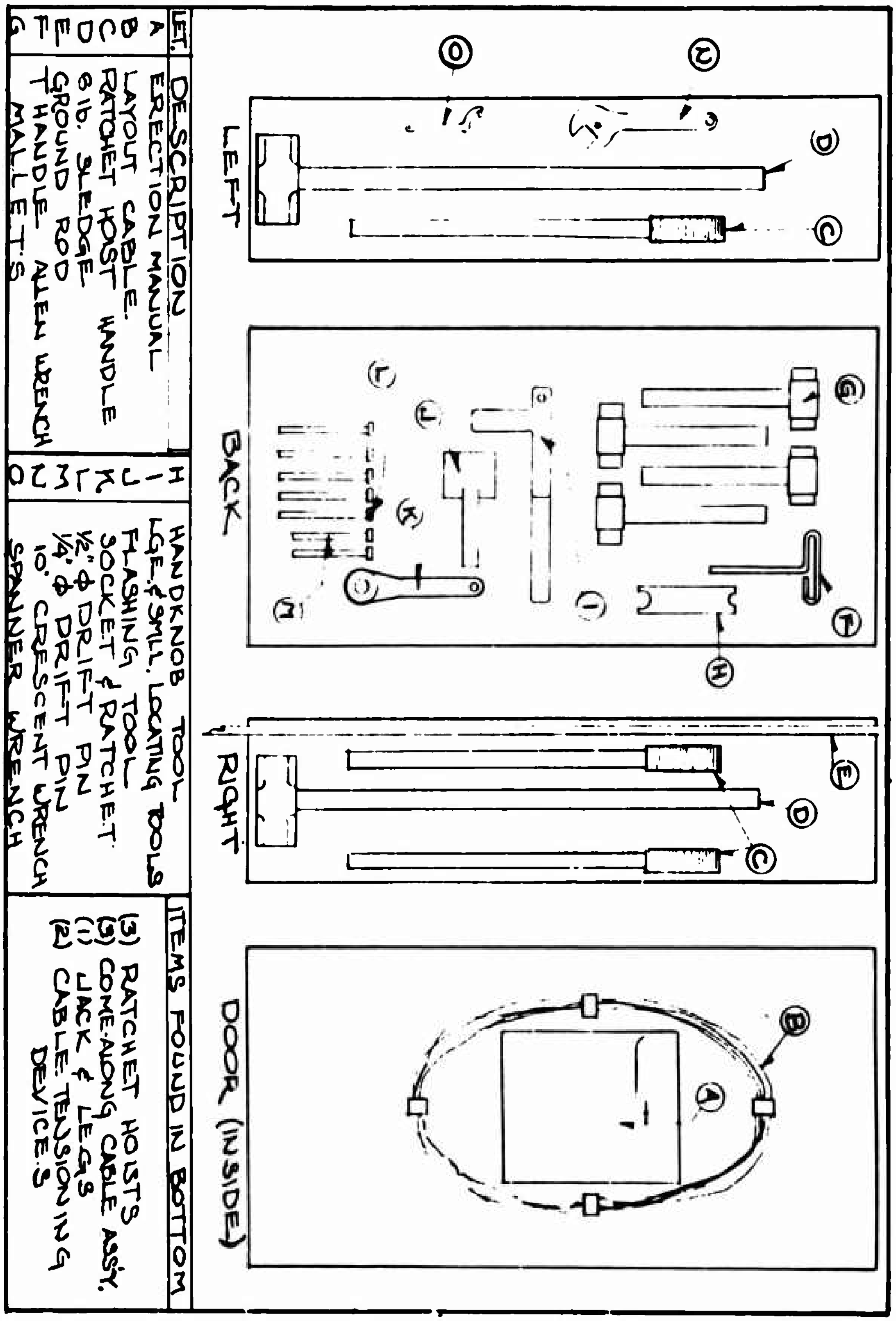


Figure 84. Tool Placement

K. ARCH BEAM FLASHING

The last procedure in the erection of the ninety (90) foot span hangar is the attachment of the arch beam flashing.

On the ninety (90) foot span evaluation arches, a basic design change eliminated the fixed fabric flashing on the panels and the tension lines in the counterflashing. The arch beam flashing consists of 1/2" thick Ethafoam panels covered with fabric and joined together with fabric hinges. Each arch beam flashing consists of fourteen of these panels. A continuous seal between the arch beam flashing and the panels was achieved by permanently affixing a "quick-edge" steel reinforced vinyl extrusion to the edge of the fabric flashing and an aluminum extrusion on the edge of the panels and engaging the "quick-edge" to the aluminum extrusion. In principle, this change was an excellent one. In test erection, greater difficulty than anticipated was encountered in attaching the "quick-edge" over long distances. The "quick-edge" is also susceptible to accidental crushing and deforming which further slows up erection. Both of these drawbacks seem to be a product of the small physical scale of the extrusion.

The correct attachment of an arch beam flashing requires the services of three (3) men. One at the top of the arch, one half-way down the spacers and the third on the ground unfolding the flashing. (Fig. 85) The flashing is pulled over the arch and positioned on top of the arch beams and spacer bars until both ends are equidistant from the ground. Now two (2) men are required on top of the arch. Working down both sides simultaneously, they attach the flashing "quick-edge" to the panels. (Fig. 86) When the arch becomes too steep to work safely the flashing is straddled. (Fig. 87) The final step is to sandwich the Velcro on the ground panel flashings in between the Velcro layers on the arch beam flashing. (Fig. 88)

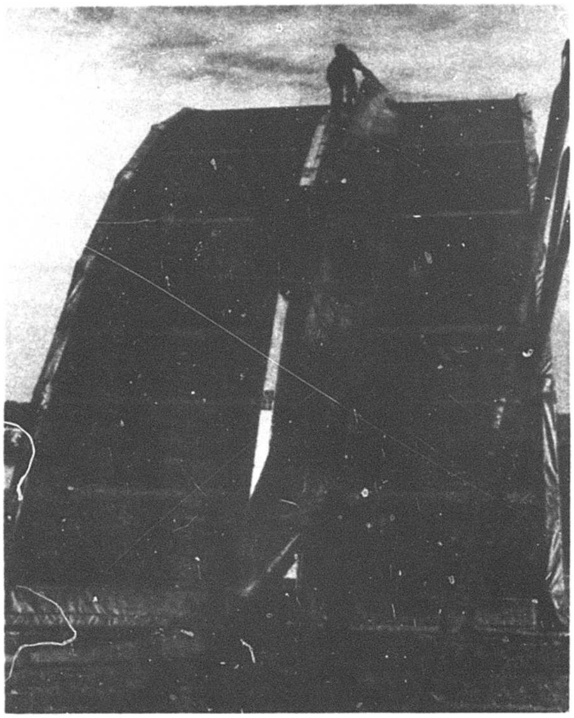


Figure 85. Placement of Arch Beam Flashing

Figure 86. Attachment of "Quick-Edge"

NOT REPRODUCIBLE

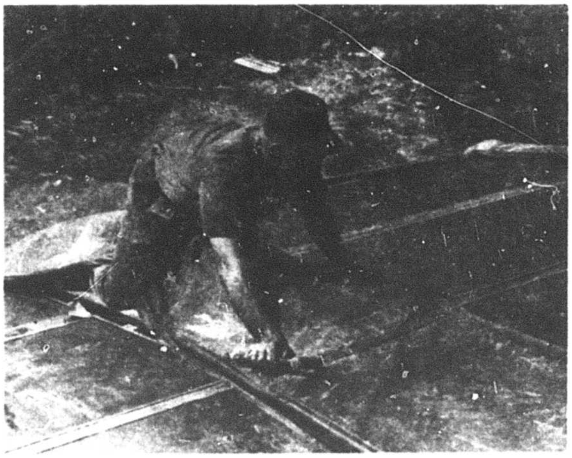


Figure 87. Straddle Position for Attachment of "Quick-Edge"

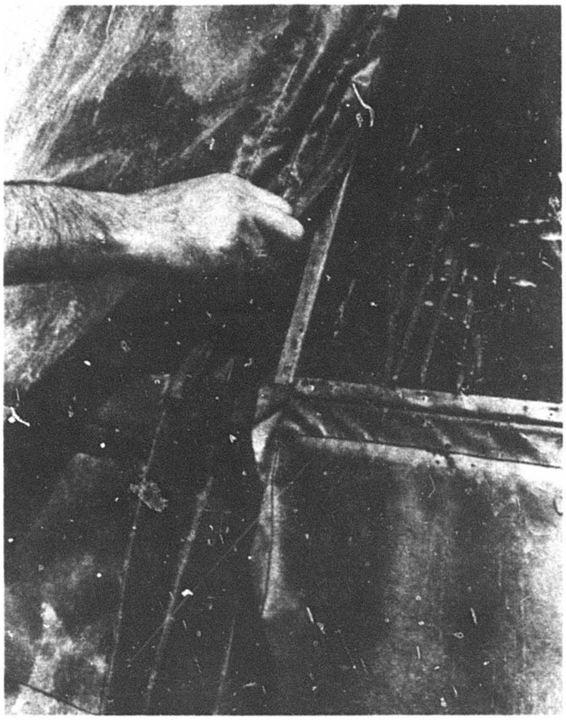


Figure 88. Final Attachment of Arch Beam Flashing

IV

PROTOTYPE PRODUCTION

A. DRAWING STATUS

To comply with contract AF33(615)3242, a complete set of form 2 drawings were furnished for use in the component fabrication of all pieces used with the ninety (90) foot span evaluation segment.

After delivery of the hangar segment, a complete set of 108 full size reproducible drawings, one set of 108 aperture cards and three sets of 108 blue line prints were submitted to constitute fulfillment of data requirement B013, Exhibit B-1, DD Form 1423.

B. SUBCONTRACTING

After an examination of facilities, jobs were awarded to subcontractors on the basis of competitive bids. There were six contractors who supplied the component parts.

1. Panda Products supplied the main arch beams, base pads, and personnel door panels.

2. Riehle Machine Co. supplied the main arch beam hinges, ground beams, lockdown base pads, columns, column base pads, ground angles and winches.

3. Newman Brothers supplied the lower arch beams, tool box and made the necessary revisions to hardware after the first erection.

4. Aero Canvas Products Co. supplied the two fabric end walls.

5. J. B. Schaaf Co. supplied the arch beam flashing and personnel door flashings.

6. Kasley Electric Co. supplied the electrical system.

C. PRODUCTION DIFFICULTIES

Newman Brothers experienced a considerable amount of difficulty with the material used in manufacturing the lower arch beams. After competitive bidding the first order for material was placed with Reynolds Aluminum. During the cutting process it was discovered that the beam dimensions were inconsistent preventing proper

alignment of hinge elements. The principle problem was the twist, although the depth and flatness were also questionable. At the request of the University, a Reynolds representative inspected the delivered stock and agreed to replace it. Within a few days the replacement material was received. It was found to have the same dimensional problem, and to be from the same mill run. Again, the Reynolds representative inspected the material and agreed to replace it, but a six week delivery was quoted. To reduce any further delay and to avoid additional charges from Newman Brothers, an order was placed with the local Alcoa distributor. A ten day delivery was promised. Upon delivery the material was inspected and found to be satisfactory. This example was explained in detail to emphasize the importance of correct dimensional tolerances for the materials used in the structural components of the ninety (90) foot span hangar.

Aero Canvas Co. also experienced fabricating difficulties. The openable end wall was checked and appeared to be constructed correctly. After delivery, and during the first test erection, it was apparent that two modifications were necessary. The center dart was not wide enough, creating a lot of fabric stress with the end wall in the closed position, and when raised, preventing the end wall from opening to the designed height. The upper fabric and "quick-edge" flashing section was not cut correctly and would not close-out around the personnel door panels. The end wall was returned to the manufacturer for revisions.

The fixed end wall was delivered several days later due to a miscalculation in the initial cutting of the fabric. After the first field test it also had to have some minor revisions. The upper fabric and "quick-edge" strip was cut incorrectly on this end wall too, thus preventing proper close-out attachment to the panels. This revision was made in the field by the University's representatives.

The openable end wall was returned too late for testing before delivery to Wright-Patterson AFB. It was discovered during this later field test that the upper fabric and "quick-edge" close-out strip was still incorrect and needed modifications.

J. B. Schaaf was contracted to fabricate two complete upper close-out sections. Replacement was necessary because modifications made to the "quick-edge" created leakage at every joint.

There were several cases of minor tolerance difficulties at Riehle Machine Co. These were easily corrected in their shop prior to acceptance.

V

FIELD TESTS

A. INITIAL ERECTION

The first erection of the two arch evaluation segment took place on 15 June 1970. Six representatives from the University of Cincinnati Design Research Collaborative were present for a two and one-half week test period, (15 June thru 30 June, 1970). This test erection was originally scheduled for 15 February to 15 March, 1970. Due to fabrication difficulties, it was rescheduled to the above dates.

1. Objectives

    a. Establish layout, leveling, and erection procedure.
    b. Check mechanical fit and usability of component parts before delivery.
    c. Evaluate ease and efficiency of erection and disassembly.

2. Logistics

    Upon completion, all component parts were delivered to Newman Brothers, 5609 Centerhill Lane, Cincinnati, Ohio. This sight was chosen because it provided the required 50' x 150' clear area for test erection. A minor problem was encountered by a late delivery of the openable fabric end wall. The test erection was made using only the fixed end wall, resulting in modifications being made to the openable end wall ground beams during a later erection at Wright-Patterson Air Force Base in Dayton, Ohio.

3. Erection

    The base pad layout, anchoring, and leveling was done the week prior to the test erection.

    The openable end wall arch was erected the first time without the fabric end wall to minimize difficulty in checking the mechanical fit of the panel and beam components.

    The first problem in erection was encountered when attaching the lower arch "V" trusses to the main arch beams. As the result of an unexpected amount

of "kick-out", the "V" trusses did not clamp to the main arch beams in the correct position. The arch must be drawn in as each leg of every "V" truss is added. It is necessary to use three come-along assemblies while erecting end wall arches, one on the end wall side of the arch and two on the other. The two on the interior side are used in a hand-over-hand method to eliminate all "kick-out". The correct relationship between main arch beam and "V" truss is easily determined with the locating tool. After this method was adopted, the arch went up with no further trouble.

The openable fabric end wall was then attached to the arch with the aid of a fork lift and work platform.

A revision to the center dart and personnel door flashing was necessary. The end wall was returned to the manufacturer.

After disassembly of the openable end wall arch, the fixed end wall arch and fabric end wall were erected simultaneously. The addition of 1-1/2" diameter rings to the "U" bolts at the top of the truck door column was necessary for connection of the end wall snaphooks. When the personnel door panels were placed, it was apparent that a sliding joint was necessary in the truck door ground beam. This variable length beam will accommodate any out-of-parallel condition of the truck door column and personnel door column created by uneven ground conditions.

The addition of a locating pin to the single base pads was necessary to position the personnel door ground angles correctly. The angle ends were also modified to eliminate the necessity of left and right coordination.

The fixed end wall fit correctly except for the narrow fabric and "quick-edge' strip along the top edge of the upper fabric panel. This section is the closeout between end wall and panels. The end wall was fabricated incorrectly and required a slight modification which was accomplished in the field. The "quick-edge" was cut, and wedge shaped pieces were removed from the fabric at every hinge point. This modification eliminated bunching and shaped the fabric to the correct contour for attachment to the panels.

The openable end wall arch was re-erected without the fabric because the modifications were not completed on time.

The electrical system was installed with no problem, and the arch beam flashing was attached.

After testing the hardware for the openable end wall, several modifications were needed.

The brackets for the primary lifting pulleys were cutting into the cable coating. This was corrected by changing the bracket angle.

The three barrel winches used in lifting the end wall were also modified. Cable guides were welded to each barrel directing the cable away from the barrel edge.

As the end wall ground beams were lowered, the beam carriers started binding on the columns. This problem was corrected by replacing the aluminum carrier angles with stainless steel ones and increasing the sliding clearance.

4. Disassembly

The two arches were dismantled much faster than they were erected. The end wall was lowered as the arch was disassembled. Three hours were required to establish a packaging procedure. All components were stacked and banded to three 463L pallets for delivery to Wright-Patterson Air Force Base.

B. ERECTION AND PRESENTATION AT WRIGHT-PATTERSON AIR FORCE BASE

The two arch evaluation segment was erected 30 June thru 3 July, 1970. Five representatives from the University of Cincinnati were present to work in conjunction with the Air Force Civil Engineering Center.

1. Objectives

   a. Delivery of the two arch prototype for testing and evaluation.
   b. Assist and explain erection techniques to a crew of Air Force personnel.
   c. Demonstrate erection procedure and design characteristics to the Air Mobility Program Office.

2. Logistics

The hangar segment was transported from Cincinnati to Wright-Patterson by flat bed truck. While in route, the load shifted damaging some of the panels. Two of the three pallets had to be unpacked before they were removed from the truck. Twenty-six of the fifty-six sandwich panels received minor damage to the aluminum edging and flashing.

3. Erection

A crew of seven enlisted men was provided to aid and observe the erection procedure. They worked unusually long hours with exceptional skill and interest.

The site was inspected and the base pads laid out prior to the delivery of the panel and beam components. The crew experienced an extreme amount of difficulty setting and anchoring the pads. The ground was hard and rocky; the arrowhead anchor driving tool did not work at all. An unseccessful attempt was made to use a 90 pound air hammer, and finally the anchors were driven by hand with a sledge hammer.

The fixed end wall and arch were erected first. No problems were encountered until the truck door was tested. The columns on either side of the ground beam were so out of parallel the door would not open to the designed height. This out-of-parallel condition resulted from the site being less level than the specified tolerance. It was decided that the truck door ground beam could be detached from the columns with no adverse effect to the operation of the door. The carriers were removed and the door operated with no further problems.

After erecting the first arch, the crew understood the system and became very interested in this type of construction. The only difficulty experienced in the initial erection of the openable and wall arch, was a misalignment of the final beam and panel segment with the base pad. This was relieved by the adjustment provided at the base pads.

The openable end wall lockdown base pads had to be altered since arrowhead anchors were unable to be driven along this side, and there were no pro-

visions made for shear stakes. Four 7/8" diameter holes were punched in each pad and they were secured with 24" long stakes.

This was the first test erection of the completed openable end wall arch segment. It was necessary to add 1-1/2" diameter rings to the sliding clips on the columns to allow the fabric to open to the designed height. A considerable amount of trouble was experienced when the end wall was lowered. The ground beams were binding on the column tracks much worse than they did when the hardware was tested at Newman Brothers. Like the truck door ground beam, the carriers were removed with no adverse affect to the operation of the end wall.

The presentation to the Air Mobility Program Office was held Friday, 3 July 1970, at 10:30 a.m. Prior to the demonstration the last two beam and panel segments were removed from the openable end wall arch. The purpose was to demonstrate the completion of an actual erection sequence.

Ten members of the Air Mobility Program Office, two representatives from Tactical Air Command, two officers from the Civil Engineering Center, one representative from the Brunswick Corporation, and one representative from Brooks and Perkins, Inc. were present for the show. The arch was re-erected again with a minor alignment problem at the base pad. Considerable difficulty was encountered when attaching the spacer bars. It was impossible to connect the upper sixteen bars and the two arches had to be drawn together with a come-along assembly. The problem was a result of an inaccurate leveling method. A sighting device is to be developed as a part of a future contract.

In the weeks following the presentation, both end walls were removed and a new "quick-edge" and fabric strip were attached. The "quick-edge" of the fixed end wall was previously modified but it was removed and replaced with a continuous piece. The same modification to the "quick-edge" and fabric strip had to be made on the openable end wall.

BLANK PAGE

VI

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Concurrence with Provisions of Contract

a. The expansion of the fifty-eight (58) foot span maintenance hangar concept to the ninety (90) foot, F-111 size, was attainable with an increase in section of the main arch beams, hinges, and an additional lower arch and truss assembly added to the end arches. The base pads were increased in size and made adjustable to adapt to more changes in terrain.

Both end walls were redesigned as a result of greater stress from an increased area of wind loading and the necessity for a wider, flatter clear area for aircraft passage.

Minor modifications were made to panels, openable end wall base pads, and arch beam spacers.

2. Specific Areas of Improvement

a. Significant improvements were made in flashing techniques. (1) eliminating panel side flashing thus reducing panel cost, (2) using an insulated semi-rigid arch beam flashing, and (3) the incorporation of "quick-edge", a new press on close-out element, sealing flashing fabric to panel edges.

b. Surpassing contractual requirements, four personnel door panel assemblies were supplied, two to be used with each end wall. The panel assemblies close out the triangular openings created at either side of the end walls. The need for left and right coordination was eliminated by interchangeability of panels.

c. The fabric truck door is larger than the required 9' x 9' opening. It is of the overhead type and operates with a winch and cable assembly. The effeciency of this design greatly exceeds the door used in the smaller fifty-eight (58) foot span hangar. All sliding, latching and roller mechanisms have been improved or eliminated.

Preceding page blank

d. The erection gantry is considerably larger. The frame is a modified production "A" frame gantry with the addition of an aluminum "I" section across the top. The substitution of two (2)-ton chain hoists for the polyester webbing and winch method of erection has greatly improved the efficiency of operation. The use of these two independent hoists, makes possible an exact horizontal assembly of arch components.

B. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

1. Panels

The two evaluation arches of the ninety (90) foot span hangar contained thirty (30) paper honeycomb core panels and twenty-six (26) polystyrene foam core panels. Both of these were initially developed for the fifty-eight (58) foot span hangar. The substitution of an attached aluminum angle along the four (4) foot edges of the 4' x 8' panels was the only modification. This angle receives a new type of flashing close-out not incorporated in the smaller hangar.

The principle area for further development is the redesign of the aluminum edge extrusions so as to eliminate "through metal" in the panels. The lack of isolation of the inner skin from the outer skin of the panels tends to (1) reduce slightly the otherwise excellent insulation properties of the panels and (2) permit forming of condensation on the inner face of panels when temperature differences exist between the inner and outer faces.

The other major reason for redevelopment of the edge extrusion is to eliminate a protruding angle leg reducing the possibility of damage to the sealing surface of the panel.

An awareness of these needs existed before, but the necessary further development was not undertaken under this contract because of the provision that the fifty-eight (58) foot span hangar components be incorporated in the ninety (90) foot span hangar wherever possible, and that the contract cost estimates did not cover the extensive design and testing that this effort would require.

2. Openable End Wall

The principal area for further development is the redesign of the ground beam lockdown devices used to secure the end wall to the ground when closed. The objective will be to design a device with a minimum profile so as to offer no obstacle to aircraft passage.

The desirability of the removal of these potential obstacles has always been realized, but again, due to the provision encouraging employment of components of types similar to those used on the smaller hangar, no basic redesign was performed.

The new lockdown base pads, as well as having a low profile, should have the same hold down efficiency as the existing ones and should be simpler and less expensive to fabricate.

The other principal area of redevelopment is the column end of the ground beams. The addition of a roller element is needed to eliminate the binding initially experienced at the carrier elements when the ground beams were raised. After the first field test, the sliding carrier connections were removed and the end wall operated easily. During the opening process there is a lateral force to the outside of the hangar keeping the ground beams against the column. The roller element is needed to prevent dragging.

3. Spacer Bars

   Goals in the recommended design and development effort would be to increase the range of adjustment in three dimensions and, at the same time, reduce complexity and cost.

4. Flashing

   Proposed further design in this area involves the development of a new "quick-edge" extrusion. The two major design considerations are increasing the size and eliminating any steel inserts. The existing "quick-edge" is too difficult to attach in the manner in which it is used, and any impact received is damaging to the continuity of shape required for sealing. The proposed material is a medium durometer neoprene type rubber extrusion. The refinements mentioned above are essential for this type of flashing and end wall close-out system.

5. Hinges

Aluminum hinges of the type furnished with the evaluation arches will be tested extensively by repetitive cycling to determine whether or not there is a need for the addition of a steel bearing insert in the pin hole. If not, the same type of hinges will be supplied.

The small forged, steel hinges used on the lower arch and columns will be replaced with aluminum ones of the same alloy as the large hinges. This change will be beneficial to production time, cost and total weight.

6. Columns and Door Head Beam

The column shape used with the two (2) arch evaluation segment is a custom extrusion. For production purposes, it should be changed to the structural standard "I" shape used for the adapter link and lower arch beam components.

A minor revision to the column is necessary to correspond with the proposed roller fitting on the openable end wall ground beams. These changes will not affect the design of any adjacent component parts.

The door head beam utilizes the same size "I" section and for production purposes, should also be changed.

7. Sighting Device

The base pads for the ninety (90) foot span hangar are easily adjustable and may be aligned with a sighting device. The proposed device would be used as follows:

a. After positioning pads with layout cable, stake pads, drive and clamp arrowhead anchors.

b. Clip "alignment scope" to the end base pad clevis with base pad in middle adjustment position. (Fig. 89)

c. Clip "bullseye" to base pad clevis at far end with base pad in middle adjustment position (Fig. 90).

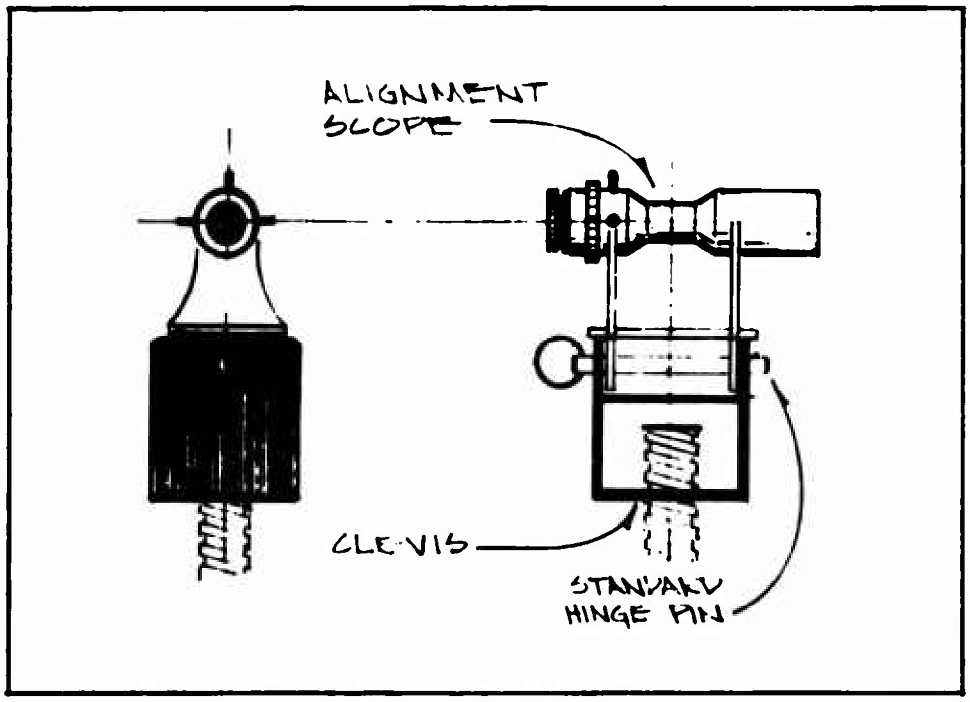


Figure 89. Sighting Device "Alignment Scope"

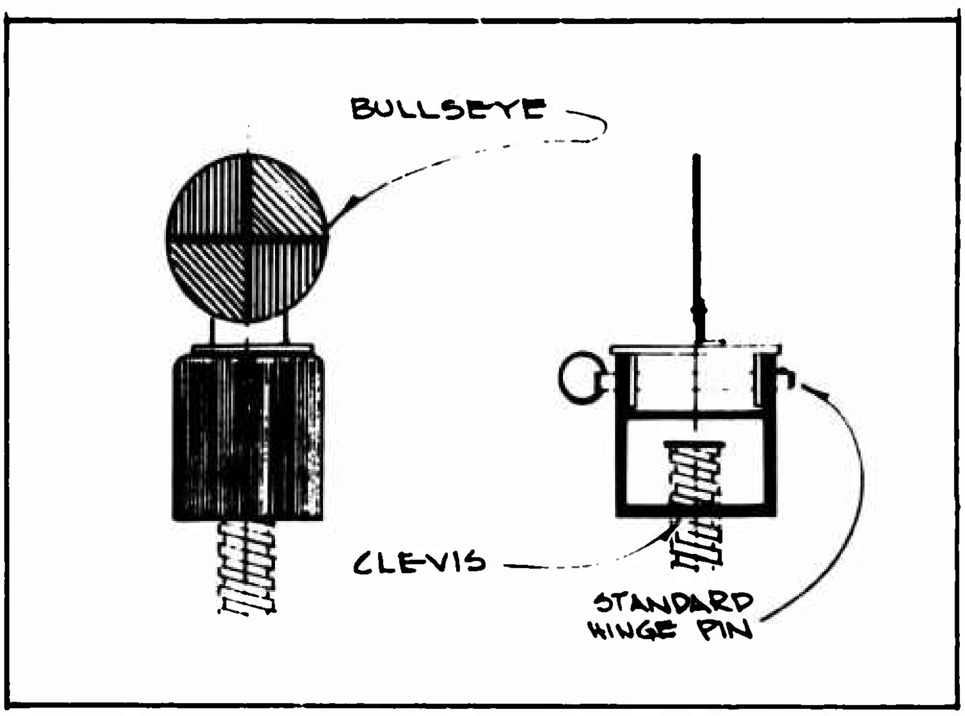


Figure 90. Sighting Device "Bullseye"

d. Align front and rear base pads by focusing the bullseye in the center of the sighting device. This is achieved by adjusting the pad supporting the bullseye, and or adjusting the pad supporting the sighting device.

e. Make three preliminary readings with bullseye at 1/4 point positions along hangar length.

f. If it is not possible to align the pads at the three preliminary reading points, return the bullseye to the end clevis and adjust either or both end base pads to eliminate the discrepancy in the preliminary readings. Repeat step "e."

g. When all three preliminary readings can be made, continue to align the remaining base pads.

8. Erection Gantry

Two minor modifications are necessary to improve the performance of the gantry system.

a. An addition of a ladder to each side of the frame to ease the placement or removal of the chain hoists.

b. Larger and wider wheels to increase footprint area and to assist in passage over base pads.

The preceding list of recommendations has been brought forth in a request for further development and fabrication of a complete ten (10) arch hangar. The components needed for this exercise are as follows:

Arch Beams:

Type 1 - Main Arch Beam — Quantity: 280
9.9" x 5.750" I-beam
7' 7.750" long

Type 2 - Lower Arch Beams — Quantity: 20
3.5" x 5.0" I-beams
7' 1.50" long

Columns:

Type 1 - End Wall — Quantity: 4
3.5" x 5.0" I-beams
10'-2" long
(2 pieces: 7'-2" and 3'-0")

Type 2 - Truck Door   Quantity: 1
3.5" x 5.0"   I-beams
15'-9" long
(2 pieces: 7'-9" and 8'-0")

Door Head Beam:

Type 1 - 3.5: x 5.0" I-beam   Quantity: 1
10'-11.125" long
(3 pieces: 8'-0" and 2 pieces at 1'-10.563")

"V" Trusses: (3.5" diameter tubing, 2 pieces)

Type 1 - Stenciled "D LH-OE"	Quantity:	1
Type 2 - Stenciled "C LH-OE"	Quantity:	1
Type 3 - Stenciled "B LH-OE"	Quantity:	1
Type 4 - Stenciled "A LH-OE"	Quantity:	1
Type 5 - Stenciled "A RH-OE"	Quantity:	1
Type 6 - Stenciled "E RH-OE"	Quantity:	1
Type 7 - Stenciled "C RH-OE"	Quantity:	1
Type 8 - Stenciled "D RH-OE"	Quantity:	1
Type 9 - Stenciled "D LH-FE"	Quantity:	1
Type 10- Stenciled "C LH-FE"	Quantity:	1
Type 11- Stenciled "B LH-FE"	Quantity:	1
Type 12- Stenciled "A LH-FE"	Quantity:	1
Type 13- Stenciled "A RH-FE"	Quantity:	1
Type 14- Stenciled "B RH-FE"	Quantity:	1
Type 15- Stenciled "C RH-FE"	Quantity:	1
Type 16- Stenciled "D RH-FE"	Quantity:	1

Diagonal Trusses:

Type 1 - 3.5 diameter tubing   Quantity: 12
variable length

Ground Beams: 3" x 4" I-beams, U-bolts on top
flange-varying lengths

Type C - 4' long	Quantity:	4
Type D - 8' long	Quantity:	3
Types E, F, G - 8' long locking devices attached	Quantity:	6 (2 each)
Types H, I, J, K, L - 8' long	Quantity:	5 (1 each)
Type M - 28" long	Quantity:	1

Ground Angles

Type 1 - Arch 6'-10" long 2" x 2" angle, fabric and Velcro attached - 2 slots each end	Quantity:	4
Type 2 - Personnel Door 7'-5" long 2" x 2" angle, fabric and Velcro attached 1 slot each end	Quantity:	4

Base Pads:

Type 1 - Double Clevis 36" x 15"	Quantity:	18
Type 2 - Single Clevis 18" x 15"	Quantity:	4
Type 3 - Openable End Wall 12.5" x 18" with lockdown device	Quantity:	10
Type 4 - Fixed End Wall 11" x 12" with hand knob clamp	Quantity:	9
Type 5 - Column 18" x 18" with column receptor and pin to receive ground angle	Quantity:	4
Type 6 - Truck Door Column 18" x 18" with column receptor	Quantity:	1

Fabric End Walls

Type 1 - Openable	Quantity:	1
Type 2 - Fixed, contains one truck door	Quantity:	1

Arch Beam Flashing

Type 1 - 110' long fabric covered foam panels. Quantity: 9

Panels

Type 1 - Standard Panel Assembly Quantity: 120
8' x 8'
2 panels: 1 with up-hill flashing
1 with down-hill flashing

Type 2 - Ridge Panel Assembly Quantity: 10
8' x 8'
2 panels: both with down-hill flashing

Type 3 - Ground Panel Quantity: 20
4' x 8'
single panel: up-hill flashing and ground angle close-out flap.

Personnel Door Panels:

Type 1 - 7' x 8' Quantity: 4
triangular panel with door in center

Winches:

Type 1 - End Wall-Three Barrels Quantity: 2

Type 2 - Truck Door-One Barrel Quantity: 1

Arrowhead Anchors:

Type 1 - 8" - for use with arch beam base pads (4 per base pad) Quantity: 88

Type 2 - 4" - for use with end wall base pads (4 per base pad) Quantity: 76

Shear Stakes:

Type 1 - 3/4" x 24" length, for use with all base pads Quantity: 200

Erection Gantry:

Type 1 - Gantry Assembly Quantity: 1
Modified production "A" frame using two (2) 2-ton hoists and two (2) lifting clamps.

Come-alongs:

Type 1 - Come-along assembly Quantity: 3
one (1) ratchet hoist and two
(2) cable and clamp assemblies
per come-along.

Combination Tool Box and Electrical Panel Board

A. Tool Box Section Quantity: 1
Storage of small equipment
needed during erection.

B. Electrical System Section

1. Cable Assemblies

Type 1 - 3 conductor Quantity: 1
105' long male-female opposite ends

Type 2 - 4 conductor Quantity: 1
105' long male-female opposite ends

Type 3 - Light fixture Quantity: 18
assembly two (2) 150 watt lights
and one junction box

2. Junction Box Assemblies Quantity: 2
one (1) with 8' male cable leads
one (1) with 12" male cable leads

Each Assembly Contains:

a. one (1), 3 conductor cable with nine (9) junction boxes for connection to light fixtures

b. one (1) 4 conductor cable with nine (9) outlet junction boxes

c. nine (9) junction box-to-beam clamps- one (1) per pair of outlet and light fixture junction boxes

3. Panel Board Quantity: 1
Contains 8-20 amp circuit breakers

Pulleys:

Type 1 - End Wall Lifting Quantity: 6
small beam clamp and angled
pulley bracket.

Type 2 - Truck Door Small beam clamp with long eye-bolt	Quantity:	2
Type 3 - Secondary Lifting Beam Clamps with large pulley	Quantity:	11

Cables:

Type 1 - Radial 4 different lengths clevis and chain opposite ends	Quantity:	15
Type 2 - Lifting 3 Different lengths hook one end	Quantity:	6
Type 3 - Truck Door Yoke and two (2) hooks	Quantity:	1

There are four (4) long-lead items that should be considered when fabricating the ten (10) arch maintenance hangar.

1. hinges - main arch beam, lower arch beam, column and ground beam.

2. arch beams - main and lower

3. Fabric End Walls - fixed and openable

4. Panels - standard, ridge, and ground

VII

APPENDIXES

Preceding page blank

APPENDIX A

INTERIOR ARCH RIB STRUCTURAL ANALYSIS
AND MEMBER DESIGN

The structural concept employed for the F4-size hangar (60' span) was to be adapted to the F-111 size hangar (approximately 89' span). The following is the general size of the opening and the rib configuration for such a structure. (Fig. 91)

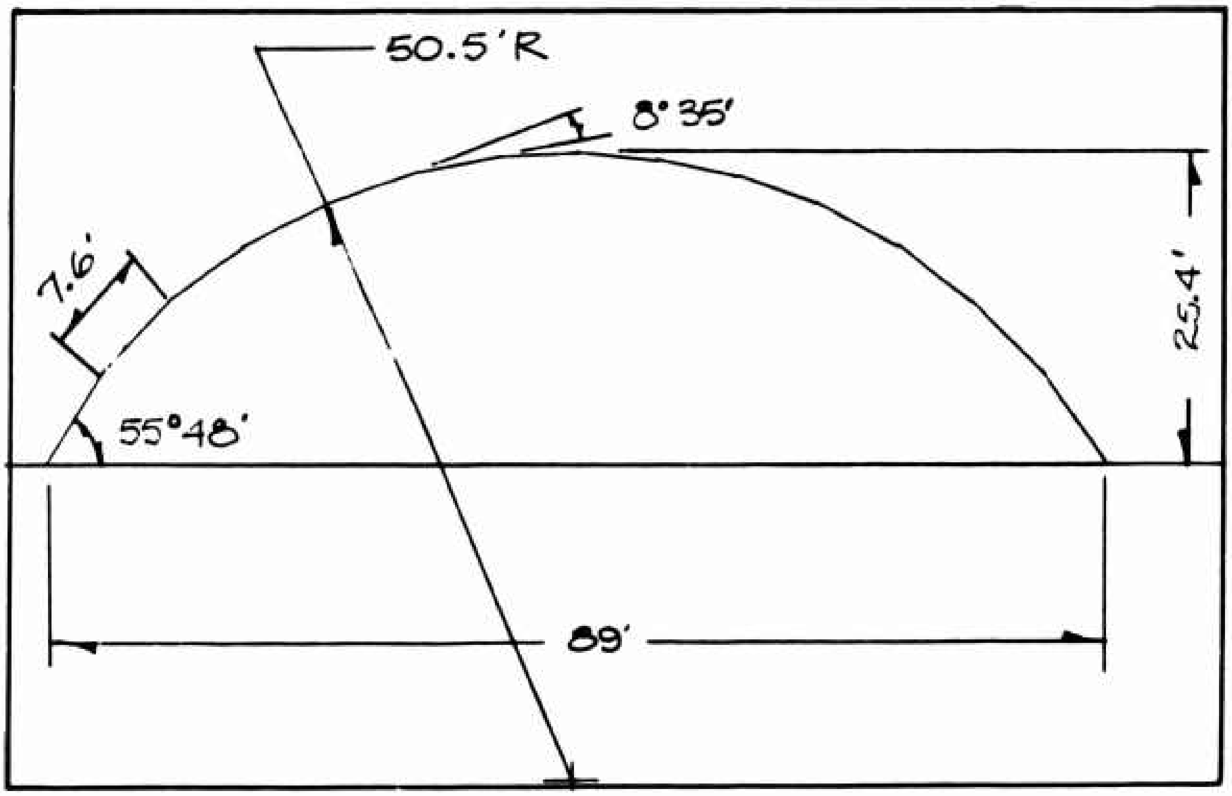


Figure 91. Configuration for Eighty-Nine (89) Foot Span Arch

Loadings

I. Dead loading: One complete arch is anticipated to be 3270 pounds - i.e., 15.4417 lbs/ft per arch rib.

II. Live loading:

A. Snow/ice 30 lbs/ft², 138.75 lbs/ft/arch rib.

Preceding page blank

B. Wind 90 mph continuous at ambient (larger than 80 mph gusts in 3 seconds) = 20.736 lbs/ft² = 95.904 lbs/ft/arch rib.

III. Loading in different zones:

A. Zone (1) $95.904 \times 0.52^{*} = 49.87$

B. Zone (2) $95.904 \times 1.07^{*} = 102.617$

C. Zone (3) $95.904 \times 0.5^{*} = 47.952$

* For $h/\ell = \frac{25'-4''}{87'-7''} = 0.28$

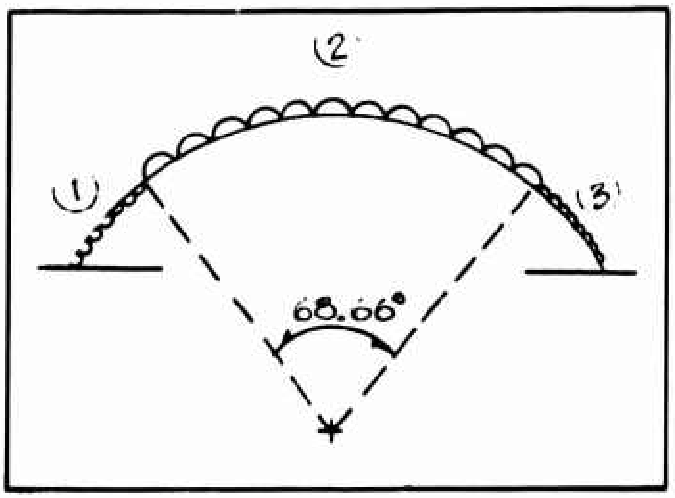


Figure 92. Loading Zones of Arch

IV. Temperature Change

Variation of 125°F after erection
Change of span by ± 1" (error in erection)

V. <u>Loading Index for Computer Programming</u>

A. Loadings:

<u>Snow</u>

(1) About 1/3 of structure covered with snow (II (1))

(2) Other 2/3 of structure covered with snow

Dead

(3) Self weight of structure

Wind

(4) Complete wind loading

B. Temperature

(5) 1/2 of structure subject to a rise in temperature of 125°F due to sunshine.

(6) Whole structure is subject to a rise in temperature of 125°F due to sunshine.

(7) 1/2 of structure subject to a fall in temperature of 75°F from ambient.

(8) Whole structure is subject to a fall in temperature of 75°F from ambient.

C. Displacement

(9) Joint 1 displaced by -1.0"x

(10) Joint 1 displaced by 1.0"x

D. Combinations

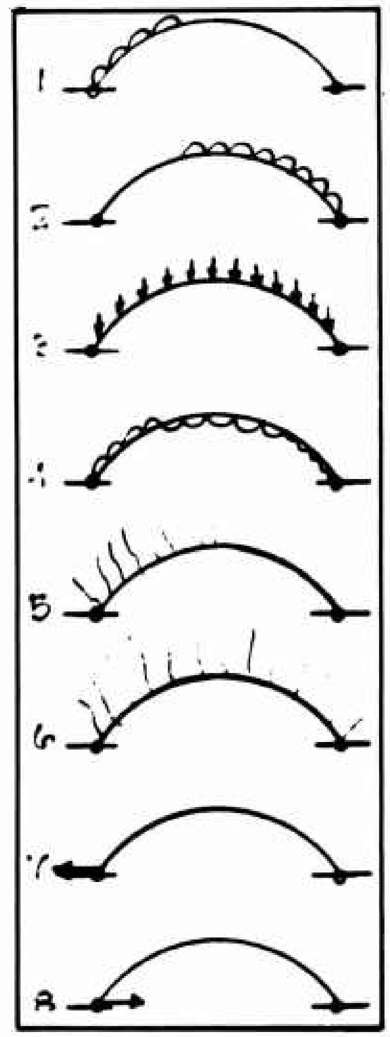


Figure 93. Index of Arch Loadings

	Maximum Results
(11) Snow (total) + dead load [(1) + (2) + (3)]	89743 lbs in {-1.86 Y; .97 X}
(12) 1/3 snow, dead, wind [(1) + (3) + (4)]	415687 lbs in {-9.14 Y; 10.98 X}
(13) 1/3 snow, dead, 1/2 wind [(1) + (3) + (4, 0.5)]	
(14) Full snow, dead, temperature drop to -75° F [(1) + (2) + (3) + (8)]	87392 lbs in
(15) (13) + temperature drop to -75° F [(1) + (3) + (4, 0.5) + (8)]	299114 lbs in

(16) Dead + wind [(3) + (4)] 232360 lbs in $\begin{cases} -4.71'' & Y \\ 5.75'' & X \end{cases}$

(17) Dead + wind + displacement 229969 lbs in $\begin{cases} 5.04'' & Y \\ 6.38'' & X \end{cases}$

(18) Full snow, dead, temperature drop to -75° F, displacement [(1) + (2) + (3) + (8) + (9)]

(19) Dead, wind, temperature rise of 125° [(3) + (4) + (6)] 228432 lbs in

(20) (19), displacement [(3) + (4) + (6) + (10)]

A structural analysis was programmed and run on a computer in accordance with the above mentioned loading combinations. The results of the critical case are shown on the following page. From that analysis, maximum bending moment, M, which would occur in the structure is as follows:

$M \approx 416000$ lbs in

Therefore, Maximum bending stress $= \frac{416000}{105.043} \times 4.95 = \underline{\underline{19850}}$ psi using the following section:

Section no.	42100-J	Alcoa	
or	8922	Reynolds	9.90" x 5.57 x 7.446 lbs

$$I_{xx} = 2\,\frac{5.75 \times (0.34)}{12} + 2\,[5.75 \times 0.34 \times (4.78)^2]$$

$$+ \frac{.24 \times (9.22)^3}{12} = \underline{\underline{105.043}}$$

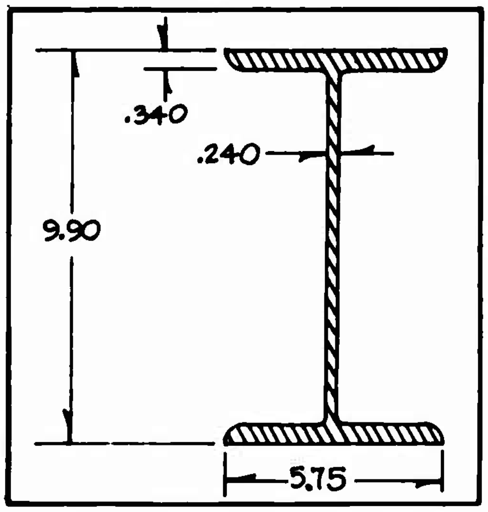


Figure 94. Main Arch Beam Sectional Dimensions

LOADING - 12

MEMBER FORCES

MEMBER	JOINT	AXIAL	SHEAR Y	BENDING Z
12	1	1355.37	3207.33	-0.11
12	2	- 390.88	-2174.69	244224.37
23	2	61.93	2208.68	-244224.44
23	3	793.94	-1039.43	391616.94
34	3	- 940.19	909.29	-391616.94
34	4	1668.25	378.83	415687.94
45	4	-1593.03	- 623.55	-415687.94
45	5	2177.00	2010.13	296175.50
56	5	-1852.59	-2312.55	-296175.50
56	6	1895.33	1645.15	116584.87
67	6	-1628.57	-1909.60	-116584.87
67	7	1654.61	1247.34	- 26672.30
78	7	-1449.92	-1480.31	26672.36
78	8	1458.68	820.67	-131086.25
89	8	-1319.55	-1029.58	131086.25
89	9	1310.79	369.94	-194594.50
910	9	-1240.90	- 561.42	194594.50
910	10	1214.86	- 100.82	-215495.87
1011	10	-1216.30	- 81.61	215495.81
1011	11	1173.56	- 585.80	-192616.94
1112	11	-1247.86	404.06	192616.94
1112	12	1189.37	- 665.63	-144076.56
1213	12	-1275.39	480.68	144076.56
1213	13	1202.48	- 752.12	- 88134.69
1314	13	-1301.26	564.23	88134.69
1314	14	1215.55	- 484.91	- 40526.53
1415	14	-1274.31	298.04	40526.50
1415	15	1177.72	- 595.05	-0.00

RESULTANT JOINT LOADS - SUPPORTS

JOINT	X FORCE	Y FORCE	Z MOMENT
1	-1890.89	2923.78	-0.11
15	169.81	-1308.54	-0.00

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	X DISP.	Y DISP.	Z ROTATION
1	0.0	0.0	-4.70
15	0.0	0.0	-2.50

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	Z ROTATION
2	5.86	-3.98	-4.04
3	9.66	-7.50	-2.37
4	10.98	-9.14	-0.27
5	10.41	-8.16	1.60
6	9.14	-4.93	2.63
7	8.16	-0.62	2.83
8	7.84	3.59	2.40
9	8.08	6.75	1.55
10	8.44	8.33	0.48
11	8.41	8.24	-0.59
12	7.58	6.81	-1.46
13	5.82	4.60	-2.06

$$I_y = 2 \left[\frac{0.34 \times (5.75)^3}{12} + \frac{9.22 \times (0.24)^3}{12}\right] = 10.76 + 0.011$$

$$= \underline{\underline{10.771 \text{ in}^4}}$$

$$A = \underline{\underline{6.1228}} \text{ in}^2$$

Axial load at section of maximum bending = F = 1668 lbs

$$f = \frac{F}{A} = \frac{1668}{6.1228} = 272.42$$

therefore, maximum normal stress = $\sigma_b + f$ = 19850 + 272.42

= 20122.42

Allowable stress for 6061-T6 = 35000 psi

therefore, $\underline{\underline{\text{F.S.} = 1.73}}$

Shear stress found to be minimal.

APPENDIX B

END ARCH RIB STRUCTURAL ANALYSIS AND MEMBER DESIGN

Shown below is the end arch configuration designed to carry the fabric end wall. Also shown are radial distributing cables used to take the tensile loads from the fabric and to apply these loads on the end arch in the pre-set direction of cables.

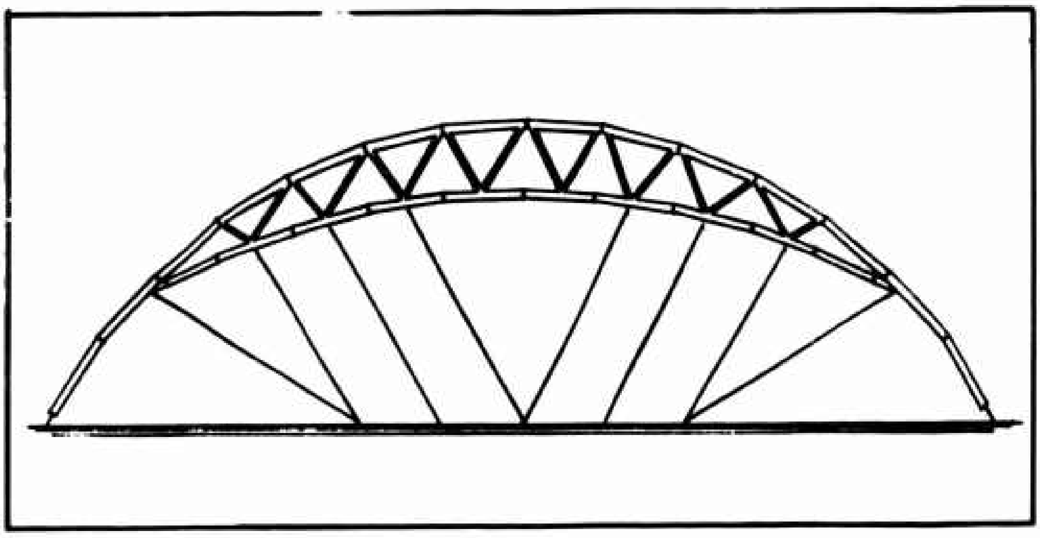


Figure 95. Openable End Arch and Radial Cable Layout

Loadings

I. Wind Load

Allowing a certain sag in the fabric and the load distributing cables, a tensile force is developed in the fabric when the end wall is subjected to a wind load. Components of this tensile force cause a vertical force V in the plane of the truss, and a horizontal load H perpendicular to the plane of the truss. (Fig. 96)

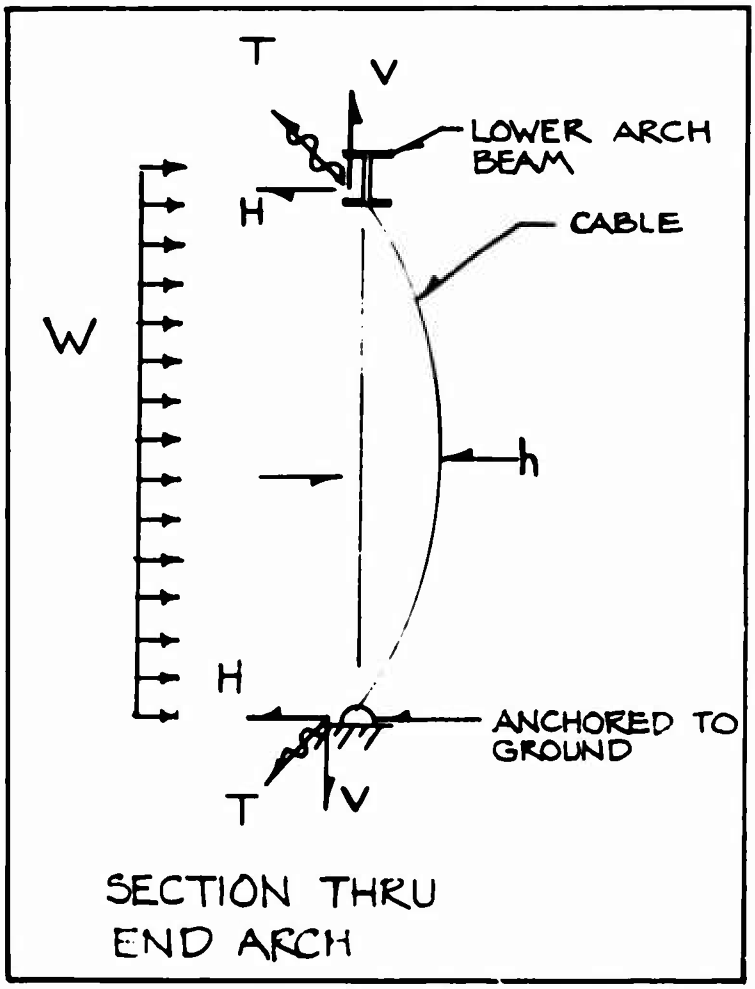


Figure 96. Wind Loading of Radial Cables and Lower Arch

The maximum tension T, for a uniformly loaded cable, is given by the following equation:

$$T = \frac{\omega \ell}{2} \sqrt{1 + \left(\frac{\ell^2}{16h^2}\right)}$$

For a 90 mph continuous wind at ambient and the given h/ℓ:

$$q = 20.74 \text{ psf and } C_d = 0.7$$

Therefore: $\omega = q \cdot C_d = 14.52$ psf

Radial distributing cables are used to take loads from the fabric and put them on the main arch in the pre-set direction of cables.

Knowing the area of fabric load which would affect each cable, the following information is set:

Cable No.	Length, ℓ	α^o	Load lbs/ft	sag, h	Load, T	Length, S
1	20.25	64.7	96.5	26"	2491.56	20'-10 1/4"
2	19.75	59	67.55	21	1994.76	20'- 1 3/4"
3	18.958	52	64.75	18	2042.18	19'- 3 1/4"
4	24.485	25	54.98	18	2821.85	24'- 8 1/2"

The resulting symmetrical loads on the end arch due to wind load are shown in Figure 97. Loads in the plane of the truss are shown on the right side and loads perpendicular to the truss on the left side.

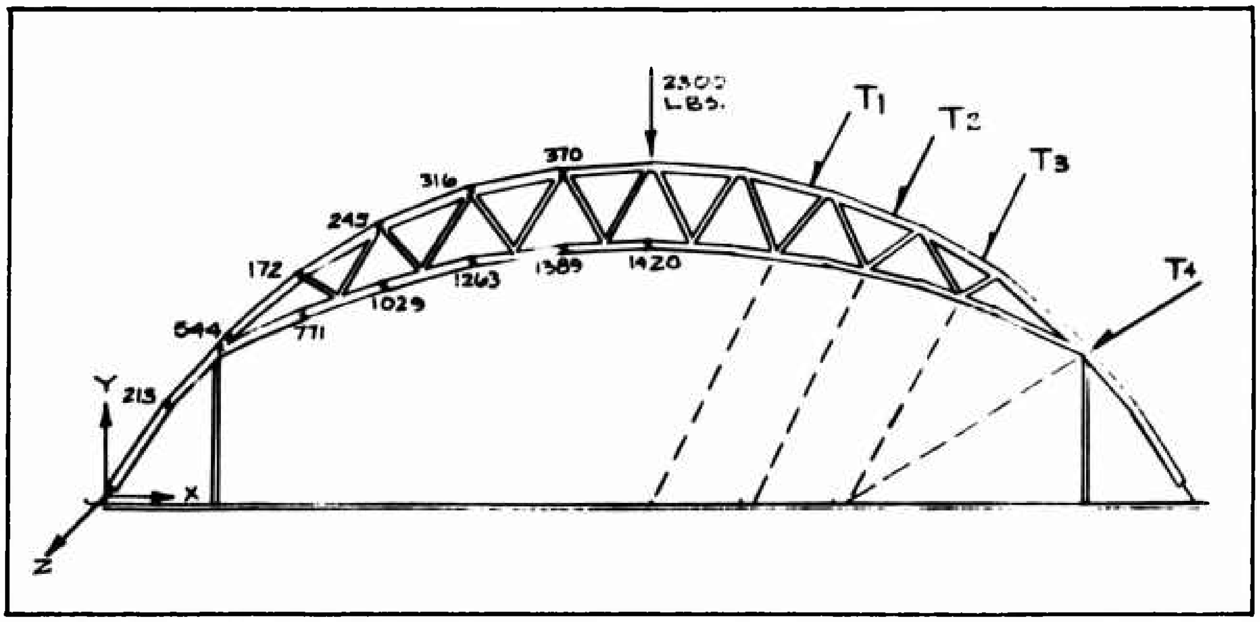


Figure 97. Symmetrical Loads on End Arch

II. Dead Load

Area of fabric, A;

$$A = \frac{(7.563 \times 50.528)\ 14-87.59\ (50.528-25.3361)}{2}$$

$= 1571.75\ ft^2$ versus 903 for F4C hangar

$$\frac{1571.75}{903} = 1.74$$

The weight of F4C hangar fabric end wall was 197 lbs. Because the area of this new end wall is 1.74 times greater, weight of fabric using aluminized 18 oz/sq yard will be 343 pounds. 200 pounds are allowed for the weight of the load distributing cables; the total end wall weight will be 543 pounds.

The structural analysis for the loadings previously indicated and the self-weight of the end arch is performed using the STRUDL problem oriented program, which is a subsystem of ICES. From this analysis, the critical forces have been tabulated below.

Maximum Results from STRUDL Analysis

a. Main Upper Arch Beam Members

M_x maximum

$M_x = 120{,}646^{\text{in-lb}}$ $P = 16{,}683^{\text{lbs}}$ M_y (negligible)

P = maximum

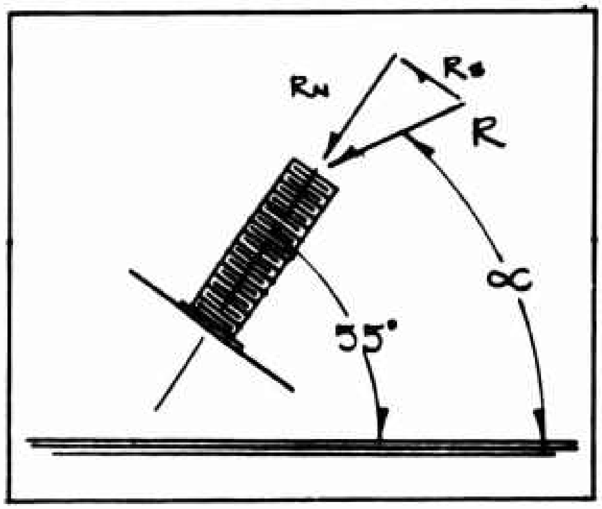
$P = 23{,}303^{\text{lbs}}$ $M_x = 10{,}375^{\text{in-lb}}$ $M_y = 13{,}665^{\text{in-lb}}$

Reaction Maximum

$R_x = 10{,}436^{\text{lbs}}$ $R = 16{,}659^{\text{lbs}}$

$R_y = 13{,}103^{\text{lbs}}$ (neglect member shear component)

Therefore loads on anchor bolts:



$$\tan \alpha = \frac{R_y}{R_x} = 1.25$$

$$\alpha = 51°30'$$

Figure 98. Main Adjustment Screw of Base Pad

R_s (shear load) $\doteq$ R sin (3°-30')

$$R_s = 16659 \times 0.061 = 1016 \text{ lbs}$$

R_n (axial load) = R cos (3°30')

$$R_n = 16659 \text{ lbs}$$

b. Lower Arch Beam Members

P and M_x maximum combination

$P = 5528^{lbs}$ $\quad M_x = 33{,}227^{in-lb}$ $\quad M_y = 20{,}975^{in-lb}$

c. Diagonal Members

P maximum

P = 3000 lbs $\quad M_x = 350.0^{in-lb}$

M_x maximum

$P = 1600^{lbs}$ $\quad M_x = 13{,}400^{in-lb}$

P and M_x maximum combination

$P = 2519^{lbs}$ $\quad M_x = 11{,}571^{in-lb}$

Member Properties and Design Checks

a. Main Upper Arch Beam Members

Check stresses using the same cross-section as in the interior arch, with the following properties as previously computed on page

$I_x = 105.04 \text{ in}^4$ $\quad I_y = 10.77 \text{ in}^4$ $\quad A = 6.12 \text{ in}^2$

$r_x = \frac{I_x}{A} = 4.12$ $\quad r_y = \frac{I_y}{A} = 1.32$

$\ell = 94.25''$

$$f_c = \frac{P}{A} = \frac{16{,}683}{6.12} = 2.73 \text{ ksi}$$

$$f_b = \frac{M_{xc}}{I_x} = \frac{120,646\ (4.95)}{105} = 5.687\ \text{ksi}$$

F_{ce} = failure as column in plane of bending

$$F_{ce} = \frac{102,000}{(\ell/r)^2} = \frac{102,000}{(94.25/412)^2} = 195\ \text{ksi}$$

Therefore: $F_c = B\text{-}D\,\frac{k\ell}{r} = 36.3\text{-}0.228\ (\frac{94.25}{4.12}) = 31.08$ ksi

Combination of axial compressive stress and traverse bending stress that will cause failure is found from the formula:

$$\frac{f_c}{F_c} + \frac{f_b}{F_b\ (1 - (f_{c/F_{ce}}))} \leq 1$$

$$\frac{2.73}{31.08} + \frac{5.687}{32(1-2.73/195.)} \leq 1$$

$.088 + 0.178 = 0.266 \leq$ adequate safety factor

b. Lower Arch Beam Member

I-beams 3.5" x 5.0" x 3.699 lbs are used

$I_{xx} = 13.59\ \text{in}^4$ $I_{yy} = 2.28\ \text{in}^4$ $A = 3.146\ \text{in}^2$

$$r_{yy} = \sqrt{\frac{2.28}{3.146}} = \sqrt{0.727} = 0.852 \qquad r_{xx} = 2.10$$

Member 40, which has the maximum load acting on it, has an effective length of 44".

$$f_c = \frac{P}{A} = \frac{5528}{3.146} = 1.76\ \text{ksi}$$

$$f_{b_x} = \frac{M_x c}{I_x} = \frac{33,227 \times 2.5}{13.59} = 6.11\ \text{ksi}$$

$$f_{b_y} = \frac{M_y c}{I_y} = \frac{20,975 \times 1.75}{2.28} = 16.10\ \text{ksi}$$

Therefore:

$$F_c = B - D\frac{k\ell}{r} = 36.3 - 0.228\left(\frac{44}{2.10}\right) = 36.30 - 4.78$$

$$F_c = 31.52 \text{ ksi}$$

$$\frac{f_c}{F_c} + \frac{f_{b_x}}{F_b\ \underbrace{(1-(f_{c_x}/F_{ce}))}_{\text{negligible}}} + \frac{f_{b_y}}{F_b\ \underbrace{(1-(f_{c_y}/F_{ce}))}_{\text{negligible}}} \leq 1.0$$

$$\frac{1.76}{31.52} + \frac{6.11}{32.0} + \frac{16.10}{32.0} \leq 1.0$$

$$0.06 + 0.19 + 0.50 = 0.75 \leq 1.0$$

c. Diagonal Members

Member 63

ℓ = 123" using 3-1/2" dia. x 3/16" Al. Tube

$I = 2.085$ $r = 1.173$

$$\frac{\ell}{r} = 104.85$$

$$F_c = \frac{102000}{(\ell/r)^2} = \underline{9.27} \text{ ksi} = 9270 \text{ psi}$$

$$f_c = \frac{P}{a} \pm \frac{M}{I}\cdot y = \frac{3000}{1.951} \pm \frac{3500}{2.685} \times 1.75 = 3818.86 \text{ psi} < 9270$$

Member 68

ℓ = 105" use the same tube as Member 63

$$F_c = \frac{102000}{(105/1.173)^2} = 12.7297 \text{ ksi} = 12729.7 \text{ psi}$$

$$f_c = \frac{1600}{1.951} + \frac{13400}{2.685} \times 1.75 = \underline{9553.79} \text{ psi} < 12729$$

Members 51 and 70

Effective length of these members is 45" and since the radius of gyration of the tube being used, r = 1.173, then allowable stress F_c would be:

$$F_c = \frac{102000}{(45/1.173)^2} = 69^{ksi} > 35^{ksi} \text{ yield}$$

actual stresses in these members are:

$$f_c = \frac{P}{A} \pm \frac{M_z}{I} \cdot y = \frac{2519}{1.951} + \frac{11571.66}{2.685} \times 1.75 = \underline{\underline{8833.18}}^{psi} < 35000$$

d. Ground Beam Design

Ground beams are supported at numerous locations by locking mechanisms shown on drawings 146-147. The only loads on the ground beams are due to tension build up in fabric at that level and that is 85.16 lbs/ft. The maximum unsupported length of ground beam is 13'.

Max. bending moment, $M = \frac{\omega \ell^2}{8} =$ 1799 lbs ft

$=$ 21547 lbs in

Using the following section, the maximum stress and deflection would be:

$I = 6.566 \text{ in}^4$

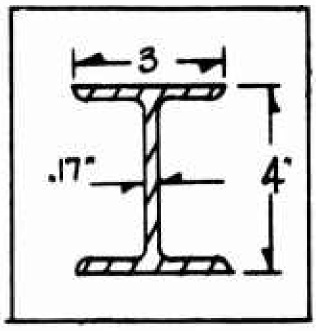


Figure 99. Ground Beam Sectional Dimensions

$$\sigma_b = \frac{M}{I} \cdot y = \frac{21547}{6.566} \times 2 = \underline{\underline{6563}} \text{ psi}$$

$$\Delta = \frac{5\ \omega\ell^4}{384\ EI} = \frac{5 \times 7.08 \times (13 \times 12)^4}{384 \times 10 \times 10^6 \times 6.566} = 0.83154 \text{ in}$$

BLANK PAGE

APPENDIX C

COMPONENT STRUCTURAL ANALYSIS

A. Hinge Design

1. Maximum force on each hinge = F

$$F = \frac{M}{d} = \frac{416,000}{9.9} = 42,000 \text{ lbs}$$

2. Maximum tensile stress in minimum net cross-section of knuckle.

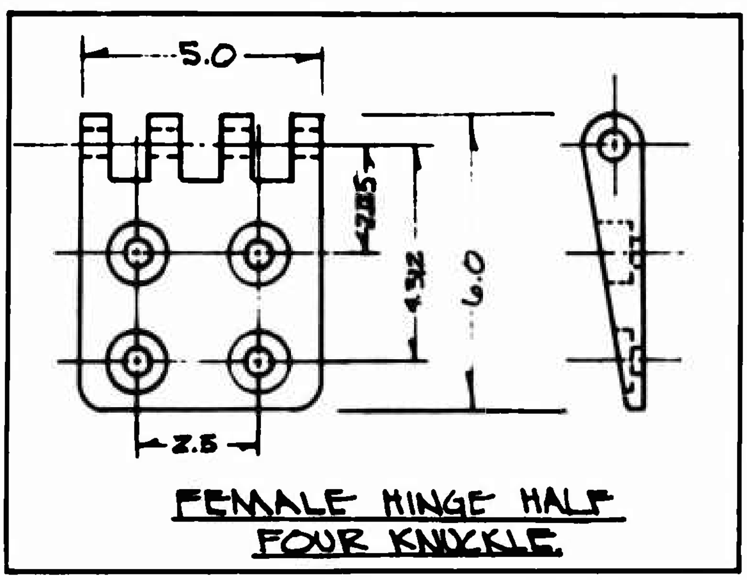


Figure 100. Main Arch Beam Hinge Dimensions

Minimum Net Section

L.H.S. $A = 2 \times 0.37 \times [3 \times 0.865] = 1.92 \text{ in}^2$

R.H.S. $A = 2 \times 0.37 \times [2 \times 0.5725 + 2 \times .6150] = \underline{1.75 \text{ in}^2}$

$$\sigma_t = \frac{F}{A} = \frac{42,000 \text{ lbs}}{1.75 \text{ in}^2} = 23,897.6 \text{ psi}$$

Preceding page blank

7075-T6 aluminum alloy, plate is adopted for hinge manufacturing.

Maximum allowable stress = 66,000 psi (tension)

Maximum allowable stress = 68,000 psi (compression)

Maximum allowable stress = 102,000 psi (bearing)

Therefore, F.S. (tension) $= \frac{66,000}{23,897.6} = 2.76$

3. Stresses in 1/2" bolt in hinge to hinge connection

Shear stress in bolt

$$\sigma_s = \frac{42,000}{6 \times 0.198} = 34,511 < 100,000 \text{ design yield}$$

Bearing stress critical in L.H.S. hinge

$$\sigma_b = \frac{42,000/3}{0.5 \times 0.865} = 32,370 < 102,000 \text{ psi for 7075-T6}$$

4. Stresses in 1/2" ϕ bolts in hinge to beam connection

Load on hinge, F = 42,000 lbs

$F_t = F \times \sin 4°15" = 42,000 \times 0.074 = 3,100$ lbs

$F_s = F \times \cos 4°15' = 42,000 \times 1.00 = 42,000$ lbs.

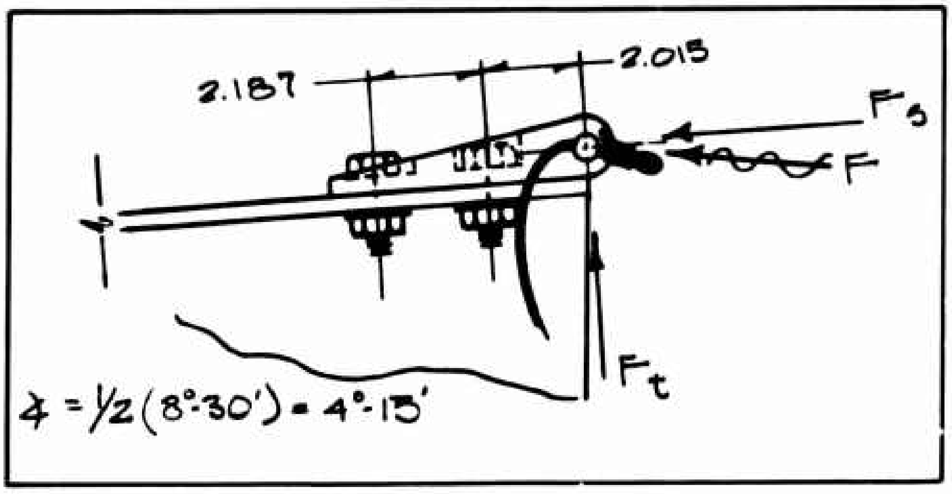


Figure 101. Stress of Hinge to Beam Connection

Since high strength bolts are required for this connection, determine if it is a bearing or friction connection. The shear force required to overcome the frictional resistance provided by four (4) SAE Grade 8 1/2" bolts is:

$$F_{slip} = k_s m n T_i$$

$$F_{slip} = 0.20\ (1)\ (4)\ (.80 \times 80 \text{ ksi} \times 0.142 \text{ in})$$

$$F_{slip} = 7.3 \text{ kips} < 42. \text{ kips}$$

Since the maximum frictional resistance is exceeded, relative slip occurs between the hinge and the beam. Therefore design as a bearing connection.

If 70% of the load is taken by the front row of bolts, the maximum shear force in the critical bolts is:

$$F_s = \frac{42{,}000\ (.70)}{2} = 14{,}700 \text{ lbs.}$$

For 1/2" bolt, the shear stress is:

$$\sigma_s = \frac{14{,}000 \text{ lbs}}{\frac{\pi(1/2)^2}{4}} = 75{,}000 \text{ psi}$$

Conservatively, if the hinge pivots about the back row of bolts due to F_t, the tensile force in each bolt in the front row =

$$F_{bolt} = \frac{(3{,}100 \times 4.3\text{in})}{(2 \times 2.1 \text{ in})} = 3{,}100 \text{ lbs.}$$

$$\sigma_t = \frac{3{,}100 \text{ lbs}}{0.20 \text{ in}^2} = 15{,}500 \text{ psi}$$

For these combined tension and shear stresses acting on the critical bolts in the hinge connection, the following interaction equation governs:

$$\left(\frac{\sigma_{tu}}{F_{tu}}\right)^2 + \left(\frac{\sigma_{vu}}{F_{vu}}\right)^2 \leq 1.0$$

F_{tu} = Ultimate tensile strength

F_{vu} = Ultimate shear strength

For SAE Grade 8 - 1/2" high strength bolts

F_{tu} = 150 ksi

F_{vu} = 120 ksi

Substituting into above interaction equation,

$$\left(\frac{15.5}{150}\right)^2 + \left(\frac{75.0}{120}\right)^2 \leq 1.0$$

$$(.10)^2 + (.625)^2 \leq 1.0$$

$$0.40 \leq 1.0$$

Bearing stresses on aluminum hinge:

$$\sigma_b = \frac{14{,}700 \text{ lbs}}{0.5 \times 0.375} = 78{,}400 \text{ psi} < 102{,}000 \text{ psi}$$

for 7075-T6

Bearing on aluminum beams:

3/32" steel sleeves are used to receive the hinge bolts

Therefore, the bearing capacity of the aluminum beams is increased.

$$\sigma_b = \frac{14{,}700}{\pi R \times 0.33} = \frac{14{,}700}{3.14 \times 0.343 \times 0.33} = 41{,}360 \text{ psi} <$$

56,000 psi for 6061-T6

5. Check bending load on hinge

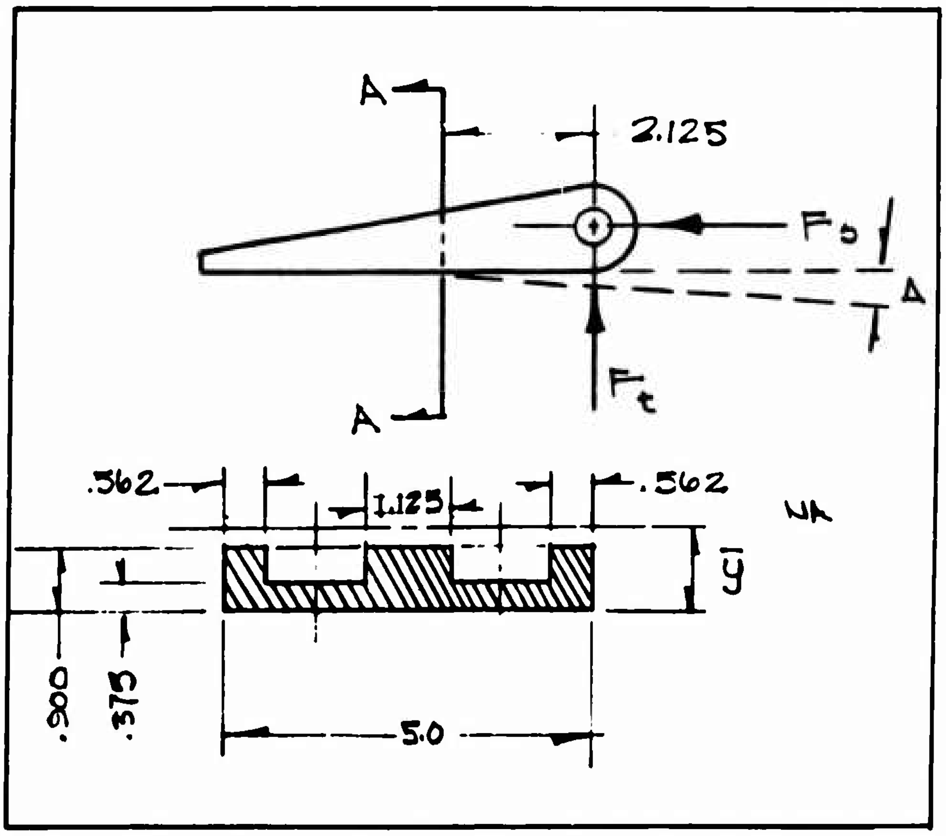


Figure 102. Cross-Section of Main Arch Hinge

Bending moment in hinge is due to traverse loading F_t and eccentricity of the axial load F_s.

$$M = 3{,}100 \times 2.125 + 42{,}000\ (0.625 - \bar{y})$$

$$M = 6{,}587 + 11{,}130 = 17{,}717^{\text{in-lb}}$$

To find $\bar{y}$:

$$2.500 \times 0.900 \times 0.450 + 2.500 \times 0.375 \times 0.187 =$$

$$2.50\ (0.90 + .375)\ \bar{y}$$

$$\bar{y} = \frac{(1.01 + 0.17)}{3.19} = 0.36 \text{ in}$$

$$I_{N.A.} = I_{0_1} + I_{0_2} + A_1(d_1)^2 + A_2(d_2)^2$$

$$I_{N.A.} = \frac{2.50 \times (0.90)^3}{12} + \frac{2.50 \times (0.375)^3}{12}$$

$$+ 2.50 \times 0.90 \times (0.09)^2 + 2.50 \times 0.375$$

$$\times (0.173)^2$$

$$I_{N.A.} = 0.15 + 0.01 + 0.03 = \underline{\underline{0.19 \text{ in}^4}}$$

Bending stress in hinge:

$$\sigma_b = \frac{M}{I} y_{max} = \frac{17,717 \times 0.54}{0.19} = 50,316 \text{ psi}$$

Maximum direct stress:

$$\sigma_a = \frac{42,000}{3.19} = 13,166 \text{ psi}$$

Maximum total stress

$$\sigma = \sigma_a + \sigma_b = 63,500 \text{ psi} < 68,000 \text{ psi}$$

Deflection of hinge subjected to bending of F_t alone is:

$$\Delta = \frac{F_t\ \ell^3}{3\ EI} = \frac{3100\ (2.125)^3}{3 \times 10 \times 10^6 \times 0.19} = \text{negligible}$$

6. Hinges used in beam connections of lower arch:

The same hinges that were used to join the main arch members in the fifty-eight (58) foot span hangar were used in the lower arch of the ninety (90) foot hangar. Since the original design load requirements of the hinge were greater than those of the lower arch, the hinges were considered satisfactory.

B. Base Pad Assembly Design

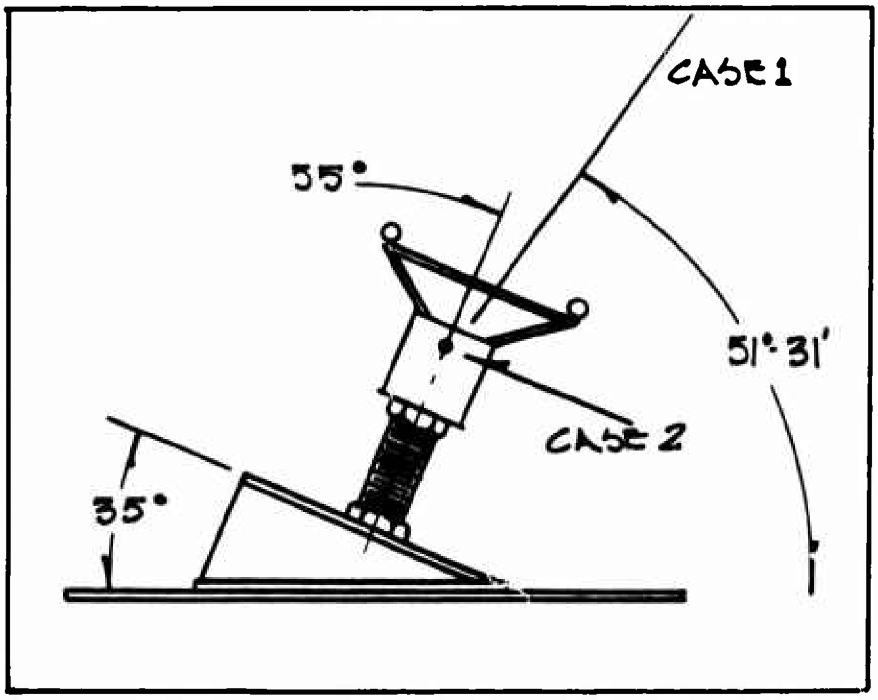


Figure 103. Base Pad Elevation

The critical loadings on the base pad shown above are as follows:

Case 1: Maximum downward load, P = 16,659 lbs (at end wall arch)

Case 2: Maximum shear load, S = 3,180 lbs

Case 3: Maximum upward load, L = 2,924 lbs (wind load on inner arches)

Laboratory tests of the original base pad components were performed by the Department of Mechanical Engineering at the University of Cincinnati. These tests revealed the need for modifications in the original design of the base pad components. The laboratory results of the tests on the original and the modified base pad components are contained in Appendix D of this report. The modified base pad components are analyzed below for resistance to the above critical loading cases.

1. Steel Shaft

2-1/4" diameter chrome plated steel bolt is used and the critical load on this is shear, S.

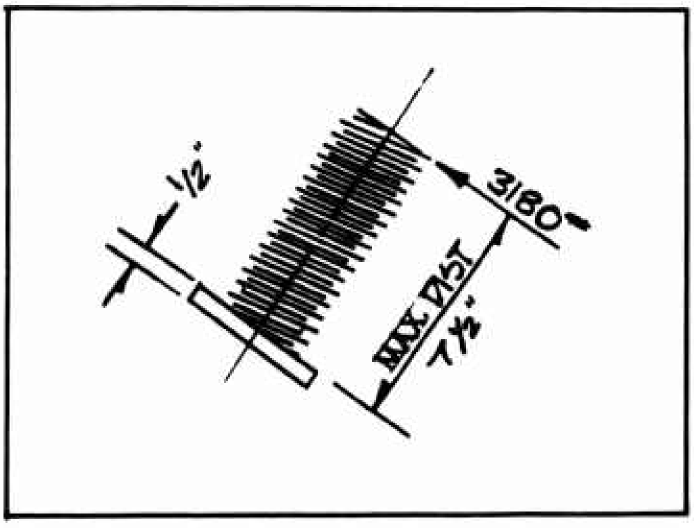


Figure 104. Maximum Bending Stress on Main Adjustment Screw of Base Pad

Maximum bending stress

$$\sigma_b = \frac{3180 \times 7.50}{I/Y} \qquad I/Y = 0.098d^3 = 0.098 \times 2.^3$$

$$I/Y = 0.784$$

$$\sigma_b = \frac{3180 \times 7.54}{0.784} = 30{,}600 \text{ psi}$$

2. Inclined Adjustment Pad

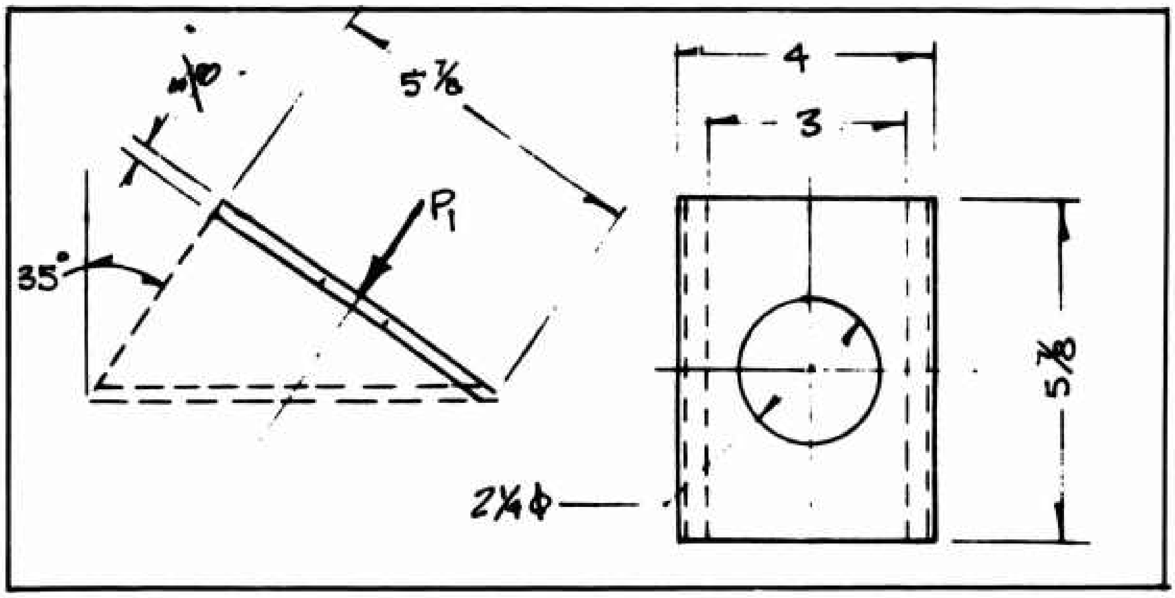


Figure 105. Horizontal Adjustment Pad Analysis

Since the load is applied to the inclined plate by the bearing of the nut on the plate, the direct shear is:

$$Area_{shear} = \text{perimeter x thickness}$$

$$= 2\pi\ (2.25/2 + 0.50) \times 0.375$$

$$Area_{shear} = 3.85 \text{ sq in}$$

$$\sigma_s = \frac{16,659}{3.83} = 4,350 \text{ psi}$$

The bearing pressure of the nut on the plate is:

$$Area_{bearing} = \pi(r_o^2 - r_1^2) = \pi(1.625^2 - 1.125^2)$$

$$Area_{bearing} = 4.30 \text{ sq in}$$

$$\sigma_b = \frac{16,659}{4.30} = 3,874 \text{ psi}$$

Check the ability of the inclined plate to resist the bearing pressure of the nut. Assuming a circular plate with a hole in the center with the load

applied over the entire annular area, the following maximum stress results:

$$\sigma_{max} = \lambda \frac{P_o R^2}{t^2}$$

For $R/r = 1.625/1.125 = 1.45$

$$\lambda = 0.900$$

$$\sigma_{max} = 0.90 \frac{3874 \times (1.625)^2}{(0.375)^2}$$

$$\sigma_{max} = 65{,}500 \text{ psi}$$

The deflection in the plate due to the applied load is given by the following equation:

$$\Delta_{max} = k \frac{P_o R^4}{Et^3}$$

For $R/r = 1.45, \quad k = 0.368$

$$\Delta_{max} = 0.368 \frac{3874. \times (1.625)^4}{30 \times 10^6 \times (.375)^3}$$

$$\Delta_{max} = 0.006 \text{ in}$$

3. Clevis Assembly

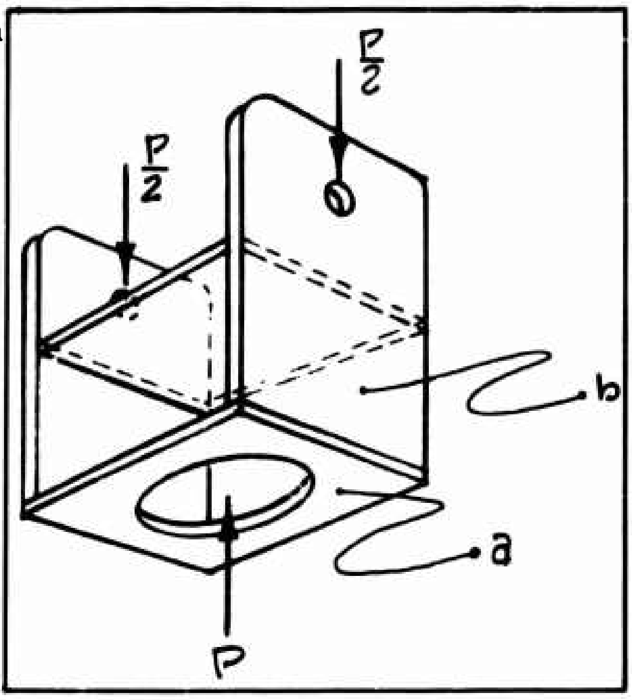


Figure 106. Clevis Analysis

a. Test results of the modified clevis assembly reveal that the plate (a) is able to withstand the design load of 16,659 lbs, plus a significant overload. The negligible deflection and end rotation of the plate for the test loads indicates a satisfactory safety factor for the design.

b. Load/holder side 'b' $= \frac{16,659}{2} = 8329.5$ lbs

Using 1/2" diameter bolt and 3/8" thick plate, the following stresses would result:

(i) Bearing stress in side plate 'b'

$$\sigma_b = \frac{8,329.5}{0.5 \times 0.375} = 44,543 \text{ psi}$$

120,000 yield for steel C-1045

(ii) Check to determine if the plate is critical in compressive buckling:

$$b/t \leq 0.7 \sqrt{\frac{k_c E}{F_y}}$$

$$b/t \leq 0.7 \sqrt{\frac{20 \times 30 \times 10^6}{120 \times 10^3}} = 49.0$$

$$b/t = \frac{5.0}{0.375} = 13.3 < 49.0$$

Therefore the plate would fail by compressive yielding before it would buckle. Determining the actual compressive stress in the plate:

$$\sigma_c = \frac{8,329.5}{5 \times 0.375} = 4,442 \text{ psi} < 120,000 \text{ psi yield stress}$$

(iii) Shear stress across bolt

$$\sigma_s = \frac{8,329.5}{\frac{\pi(1/2)^2}{4}} = 42,443 \text{ psi}$$

4. Hinge Adapter

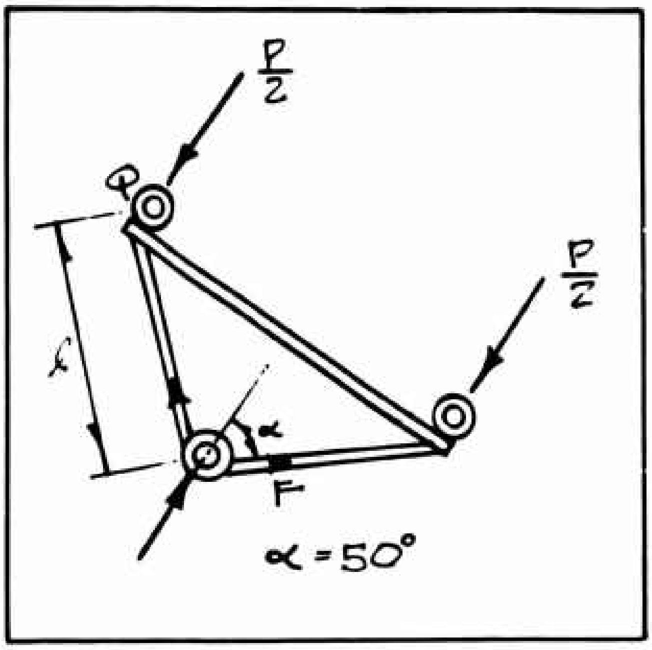


Figure 107. Triangular Hinge Adapter Analysis

$$2F \cos \alpha = P = 16{,}659$$

$$F = \frac{16{,}659}{2 \times 0.6428} = 12{,}958 \text{ lbs.}$$

$$\sigma_c = \frac{F}{A} = \frac{12{,}958}{1.87} = 6{,}929.5 \text{ psi}$$

Where A (cross section of steel) = 5" x 3/8" = 1.87 in^2

ℓ = 5.0 inches

Check to determine if the plate is critical in compressive buckling:

$$b/t \leq 0.7 \sqrt{\frac{k_c E}{F_y}} = 49.0$$

$$b/t = 5.0/0.375 = 13.3 < 49.0$$

Therefore compressive yielding controls and the 3/8" plate is adequate for the 6,929.5 psi stress.

5. Base Pad of Inner Arches

Loads per Rib on Base Pad

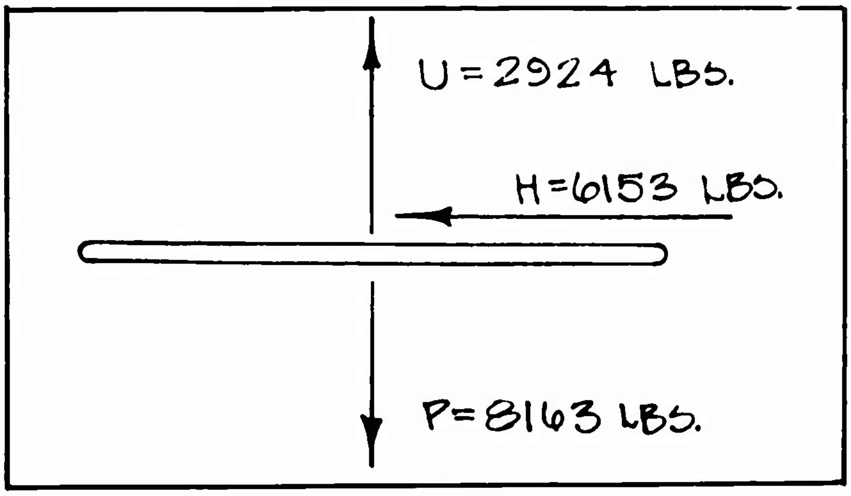


Figure 108. Loads on Inner Arch Base Pads

The uplifting force is resisted by the tie down force in the arrowhead anchors at the edge of the base pad. Therefore a moment is induced in the base plate:

$$M = \frac{PL}{4} = \frac{(2924)(15")}{4} = 10{,}965 \text{ in-lb}$$

Using t = 3/8"; I = 0.061 in^4

Therefore

$$\sigma_b = \frac{M}{I} \times y = \frac{10.965}{0.061} \times 0.187 = 33{,}614 \text{ psi}$$

The uplifting force per arrowhead anchor is one half the uplift per rib or 1,462 lbs. The horizontal thrust is resisted adequately by the two edge angles and 4 shear stakes per rib. Previous field tests indicate that the arrowhead anchors and shear stakes are able to resist the above design loads.

C. Load on Roof Panel

The maximum wind pressure on the roof panels of the 90' hangar is 22.2 lb/ft². Since the dimensions of this panel are the same as the panel used in the 58' hangar where the maximum wind pressure was also 22.2 lb/ft², the stress in the skin of the panels, the camlock loads and the connection loads will be

the same as computed on pages 254 to 259 of Volume I of this report. It is considered redundant to repeat these computations here.

Eccentric connection of the roof panels to the arch causes twisting movement of the arch ribs.

load per panel = 30 x 22.5 = 675 lbs

load per panel = $\frac{675}{4}$ = 168.75 lbs ≈ 169

Maximum twisting moment (possible)

= 169 x 2.87" = 485 lbs in/connection

= 485 x 4 = 1,940 lbs in/beam

$$J = 1/3\ (2bt_1^{\ 3} + dt_2^{\ 3}) = 1/3\ [2 \times 5.75\ (0.34)^3 + 9.9\ (0.24)^3] = 0.1962$$

$$\phi = \frac{t\ell}{GJ} = \frac{1940 \times 91}{8 \times 10^6 \times 0.1962} = 0.112 \text{ rad.} = \underline{\underline{6.4^\circ}}$$ within the acceptable limit.

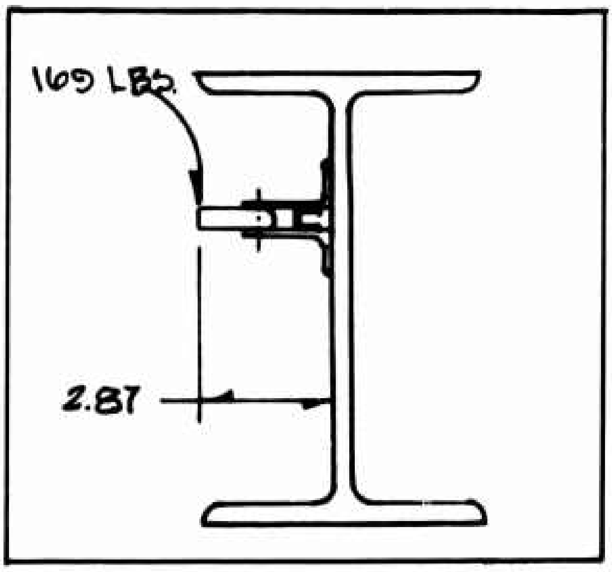


Figure 109. Main Arch Beam Camlock Analysis

D. Erection Load and Come-along Assembly

The end wall arch erection is most critical since it consists of an interior arch rib and an end wall arch rib. The end wall rib will kick-out less due to the restraining effect of the lower arch and truss assembly. During erection, a come-along arrangement is required to insure that the span of the two arch ribs is the same. The maximum horizontal kick-out force, to be resisted by the come-along assembly, naturally occurs when the end wall arch is completely assembled and detached from the base pad. An analysis using the STRUDL computer program was performed fcr the dead loads of the rib arches. The maximum horizontal reactions that the come-along assembly must provide for the interior arch rib and end wall arch rib, are shown in Figure 110 below.

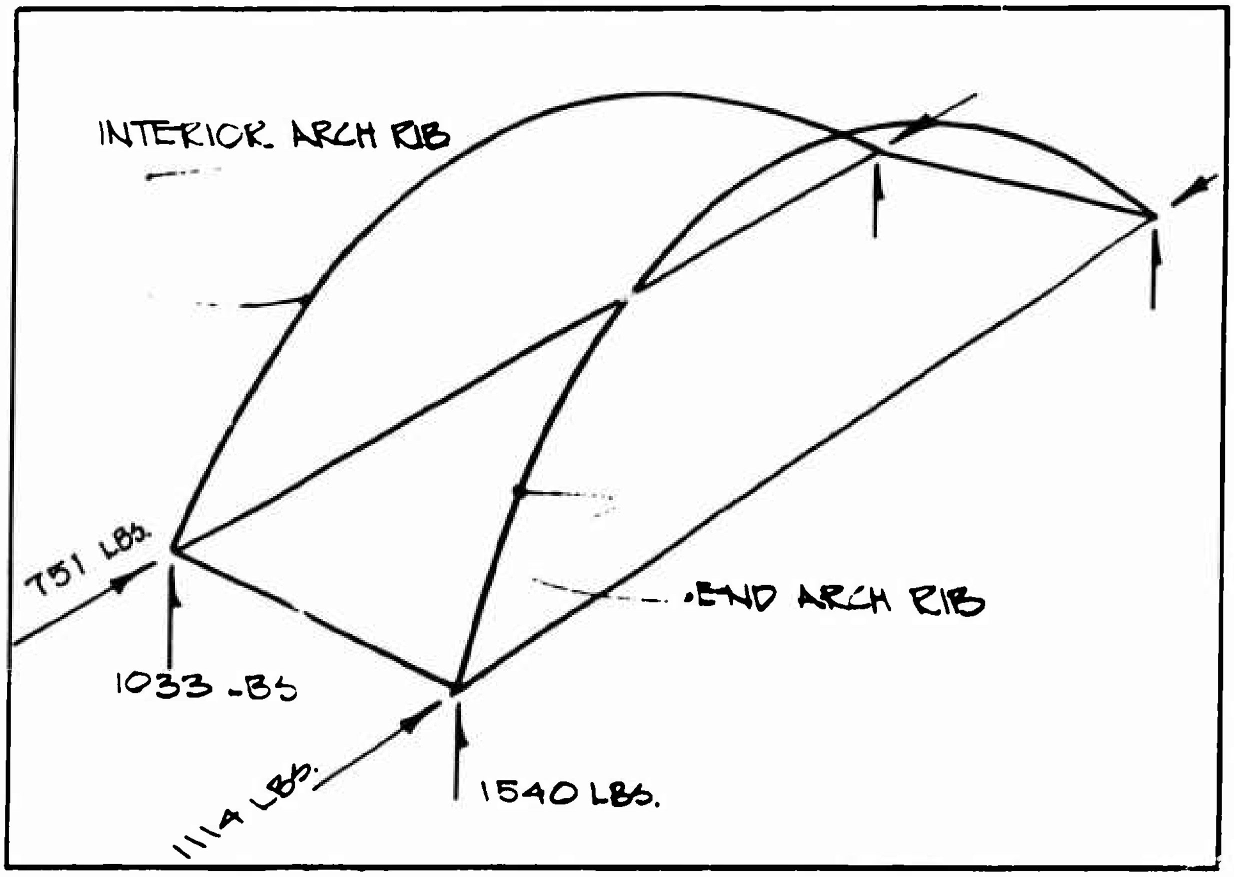


Figure 110. Reactions in Erection Process of End Wall

The capacity of the system is 2,200 pounds, whereas the maximum horizontal force required to cancel the self weight horizontal reaction is 1,114 pounds. The procedure for the use of the come-along cables to facilitate the erection of the arches, is outlined previously in this report.

E. Erection Gantry

During erection, an A-frame gantry is required to support one end of the arch assembly which is composed of two arch ribs and their roof panels. From a STRUDL analysis, for the self-weight of the end wall arch, the maximum vertical loads on the gantry were computed and are shown in Figure 111 below.

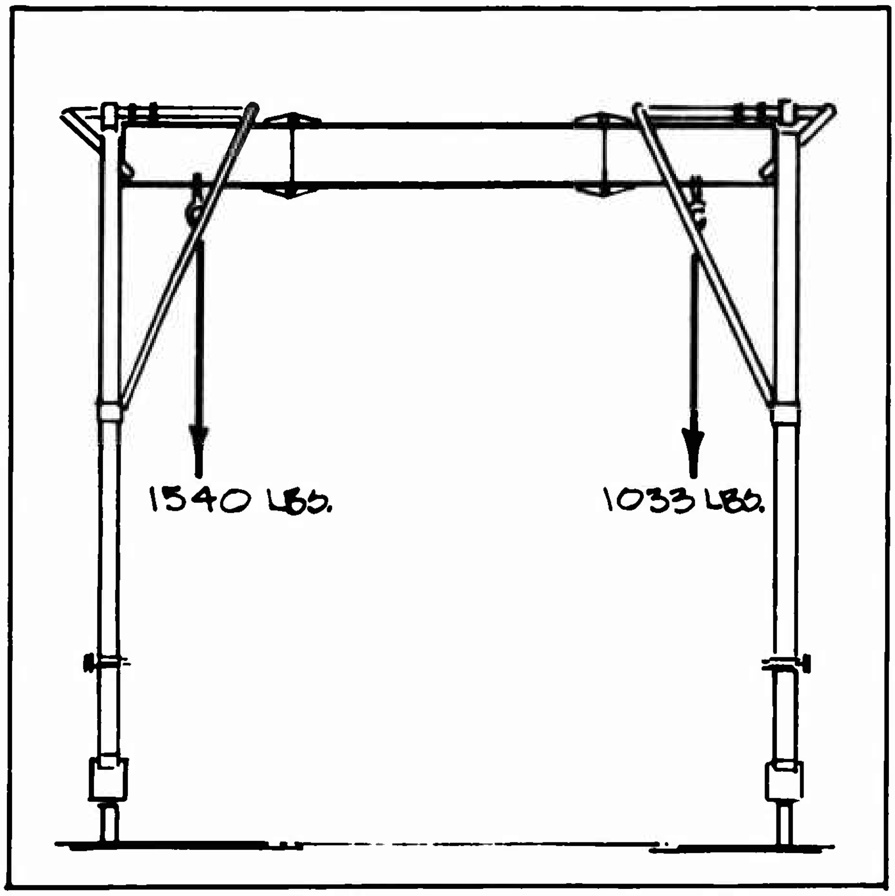


Figure 111. Vertical Loads on Gantry

The I beam used in the gantry is the same section that is used for the main arch rib:

9.90" x 5.75" x 7.446 lbs.

The maximum bending moment which occurs in the simply supported beam is:

$$M_{max} = \frac{1540(120-10) + 1033(10)}{120} \times 10 \text{ in.} = 14{,}980 \text{ in-lb}$$

The maximum stress from this moment is obviously negligible. The hinges in the beam were designed for use in the main arch rib where the moments are considerably larger than in the gantry; therefore, the hinges are adequate. The A-frames of the gantry were purchased commercially and have a combined capacity of 4,000 lbs, which is adequate to support the 2,600 pound end wall arch load.

Two - 2 ton capacity hand hoists, attached to the I-beam of the erection gantry, are used to elevate and lower an arch assembly during erection. One hoist is attached to each of the two ribs. The hoist is adequate for the maximum vertical load of 1,540 pounds.

APPENDIX D

PROTOTYPE TESTING

All new design concepts were tested and the necessary modifications made before prototype components were fabricated.

The three major areas tested were flashing, hinges and base pads. A small arch section was erected using beams from the fifty-eight (58) foot span hangar and three of the modified panels. A short section of flashing was attached and tested for leaks. (Fig. 112) The sealing characteristics of the "quick-edge" and aluminum angle were satisfactory. However, the difficulty of attachment, in actual field conditions, was not realized. The principle of this type of close-out is good, and with a change in material and physical size, the flashing will seal correctly and be almost impervious to damage.

The hinges and base pads were tested in the mechanical Engineering Laboratory and a detailed report was submitted to our office. The contents of this report are included in the following pages.

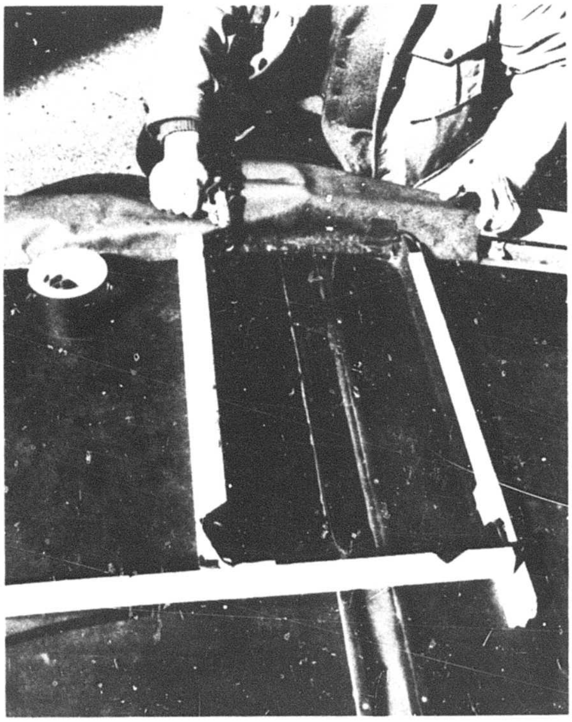


Figure 112. Water Test of Panel and Flashing

Preliminary Data Report

To

Design Research Collaborative
University of Cincinnati

Prepared by

W. R. Shapton and F. E. Espelage
Department of Mechanical Engineering
University of Cincinnati

March 20, 1970

Preceding page blank

INTRODUCTION

Tests were performed on four general component configurations, two for the base pad and two for the hinge-beam assembly. These will be identified as follows:

A. Base Pad

Case 1 - Compression load applied 3° - 29' off support screw centerline as shown in Figure 113.

Case 2 - Load applied approximately 90° to main screw as shown in Figure 114.

B. Hinge-Beam Assembly

Case 1 - Load applied so as to produce a moment placing the outside hinge in tension as shown in Figure 115.

Case 2 - Load applied so as to produce a moment placing the inside hinge in tension as shown in Figure 116.

The results of each test are described in the following sections.

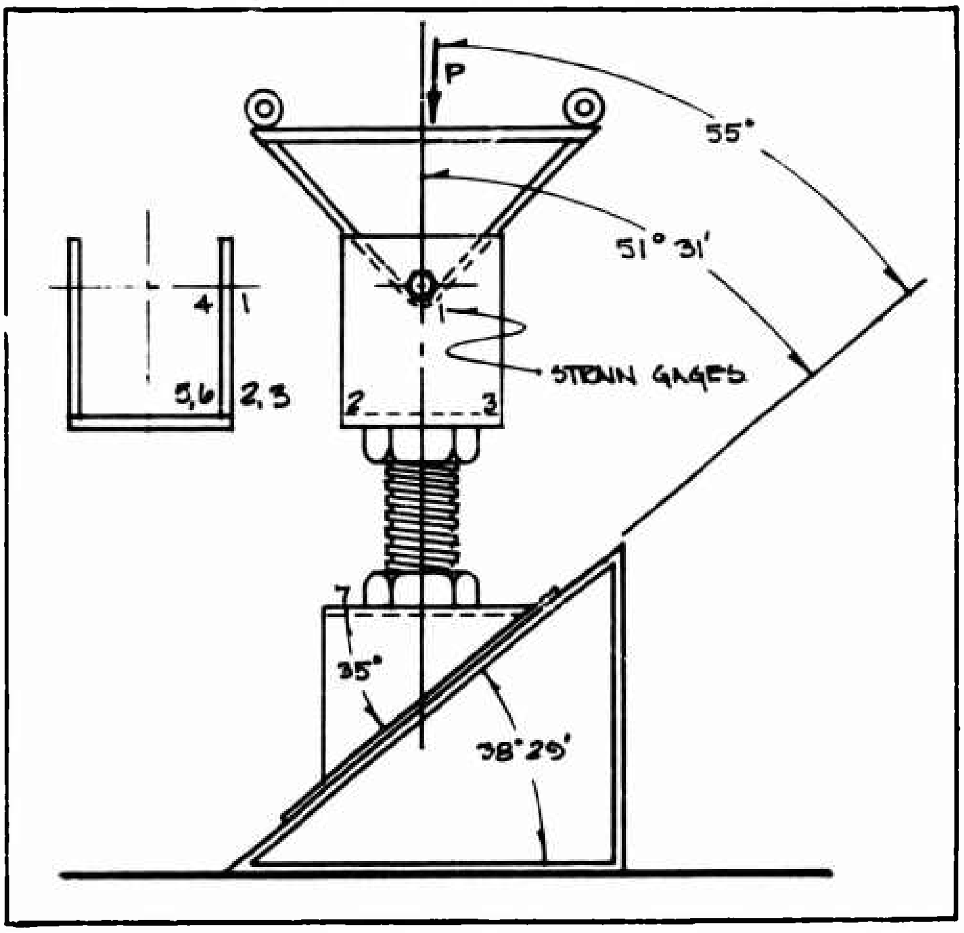


Figure 113. Base Pad Clevis Test Set-Up

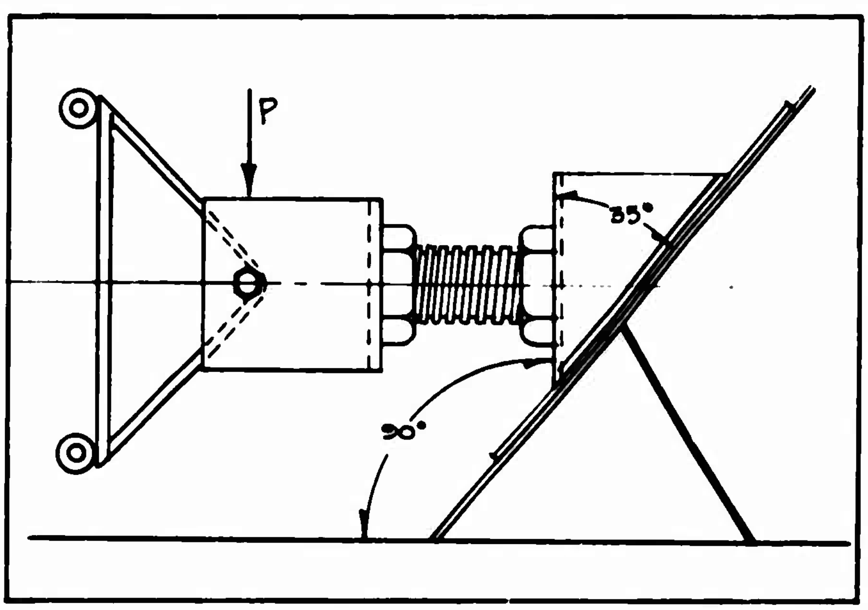


Figure 114. Base Pad Main Adjustment Screw Test Set-Up

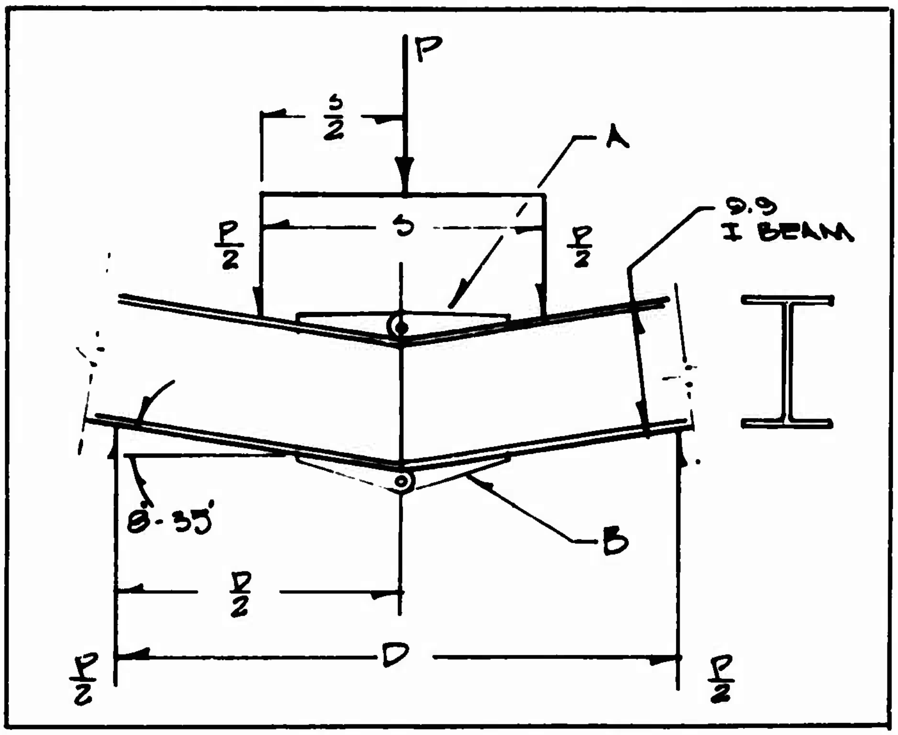


Figure 115. First Hinge and Beam Test Set-Up

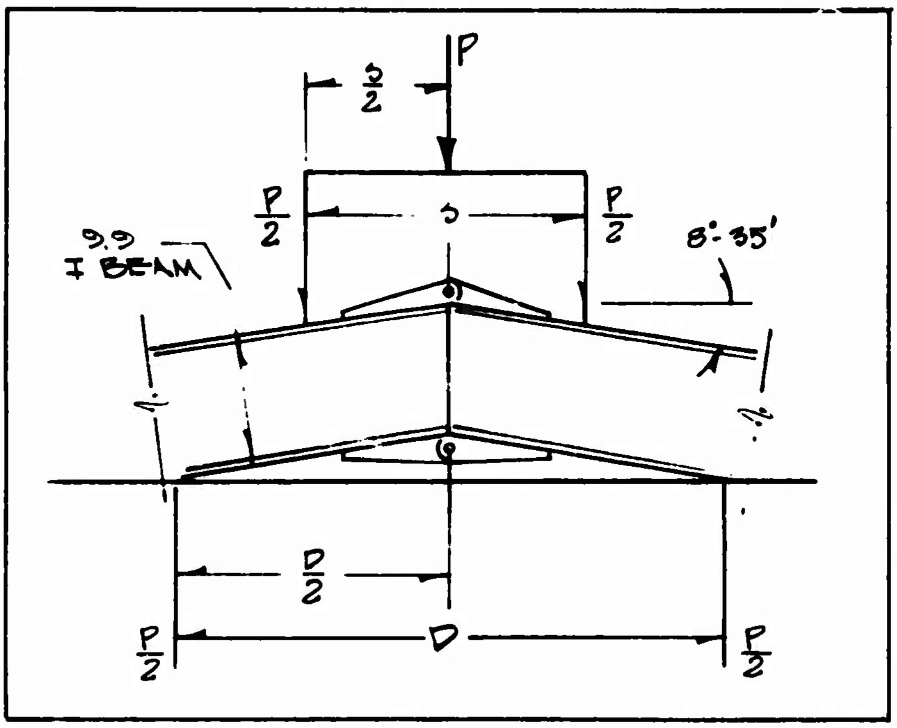


Figure 116. Second Hinge and Beam Test Set-Up

TABLE I

Gage

Load	1	2	3	4	5	6	7
0	0	0	0	0	0	0	0
250	-0025	- 0050	- 0020	+0005	+ 0065	+ 0005	-0010
500	- 75	- 145	- 75	+ 15	+ 145	+ 65	- 30
750	- 110	- 180	- 120	+ 25	+ 210	+ 125	- 40
1,000	- 155	- 250	- 165	+ 25	+ 265	+ 165	- 65
1,250	- 180	- 300	- 205	+ 30	+ 320	+ 210	- 80
1,500	- 215	- 360	- 240	+ 40	+ 390	+ 260	- 90
1,750	- 240	- 410	- 285	+ 45	+ 455	+ 300	- 115
2,000	- 275	- 480	- 325	+ 40	+ 505	+ 345	- 135
2,250	- 305	- 535	- 370	+ 45	+ 580	+ 400	- 155
2,500	- 330	- 585	- 415	+ 70	+ 665	+ 460	- 160
3,000	- 380	- 700	- 505	+ 65	+ 785	+ 550	- 205
3,500	- 430	- 800	- 580	+ 60	+ 890	+ 640	- 250
4,000	- 522	- 715	- 535	+ 130	+ 840	+ 540	- 280
4,500	- 580	- 825	- 620	+ 135	+ 955	+ 615	- 325
5,000	- 635	- 955	- 705	+ 135	+ 1085	+ 695	- 380
5,500	- 685	- 1085	- 795	+ 140	+ 1225	+ 780	- 440
6,000	- 710	- 1250	- 925	+ 145	+ 1460	+ 900	- 505
7,000	- 715	- 1720	- 1010	+ 145	+ 1570	+ 1500	- 645
8,000	- 625	-49590	-48590	+ 120	+ 49985	+47755	- 800
9,000		-51300	-50190		+ 98020	+49410	- 970
10,000		-51260	-47630		+100340		

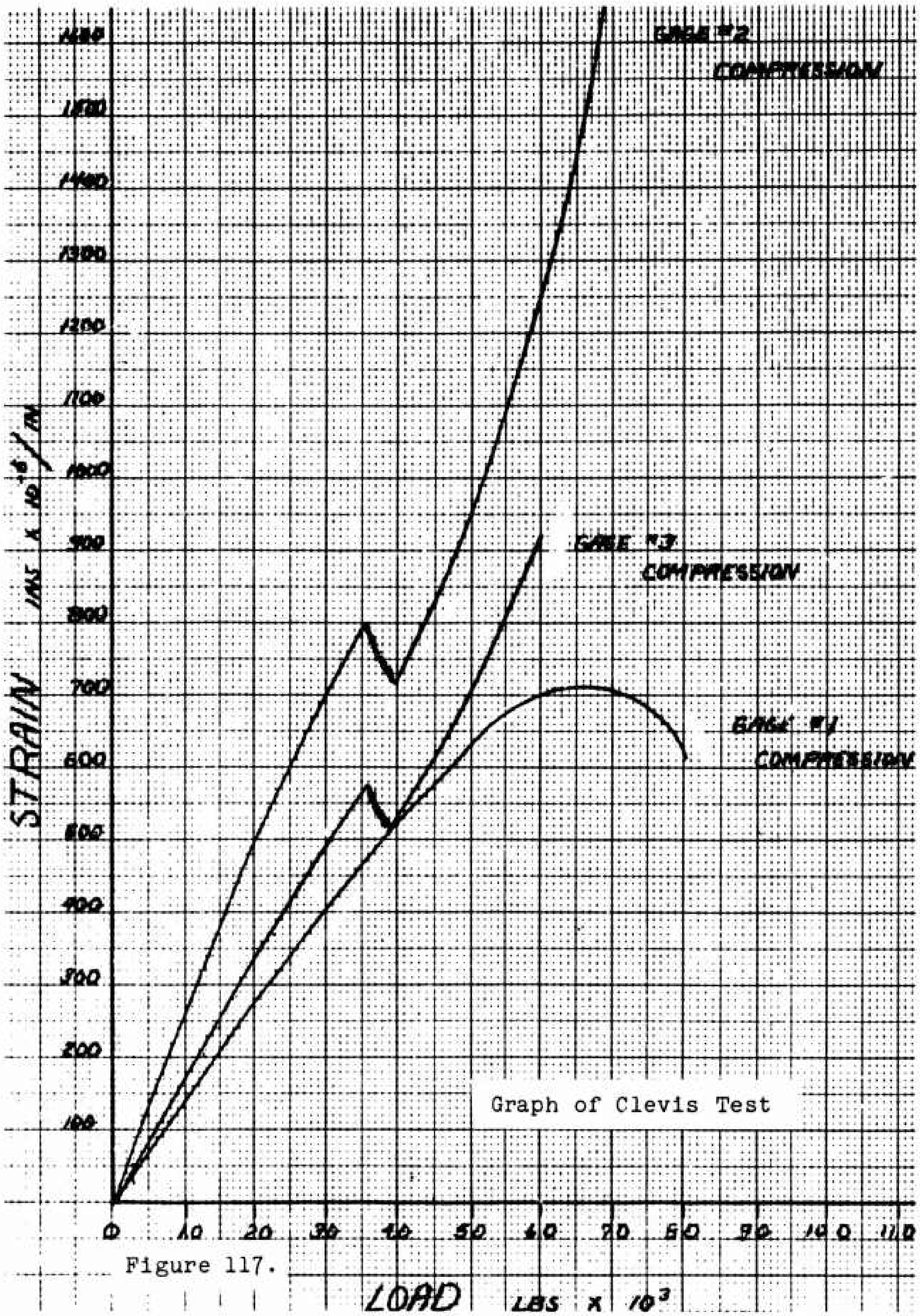

GAGE #2
COMPRESSION
GAGE #3
COMPRESSION
GAGE #1
COMPRESSION
STRAIN INS X 10^-6/IN
LOAD LBS X 10^3
Graph of Clevis Test

Figure 117.

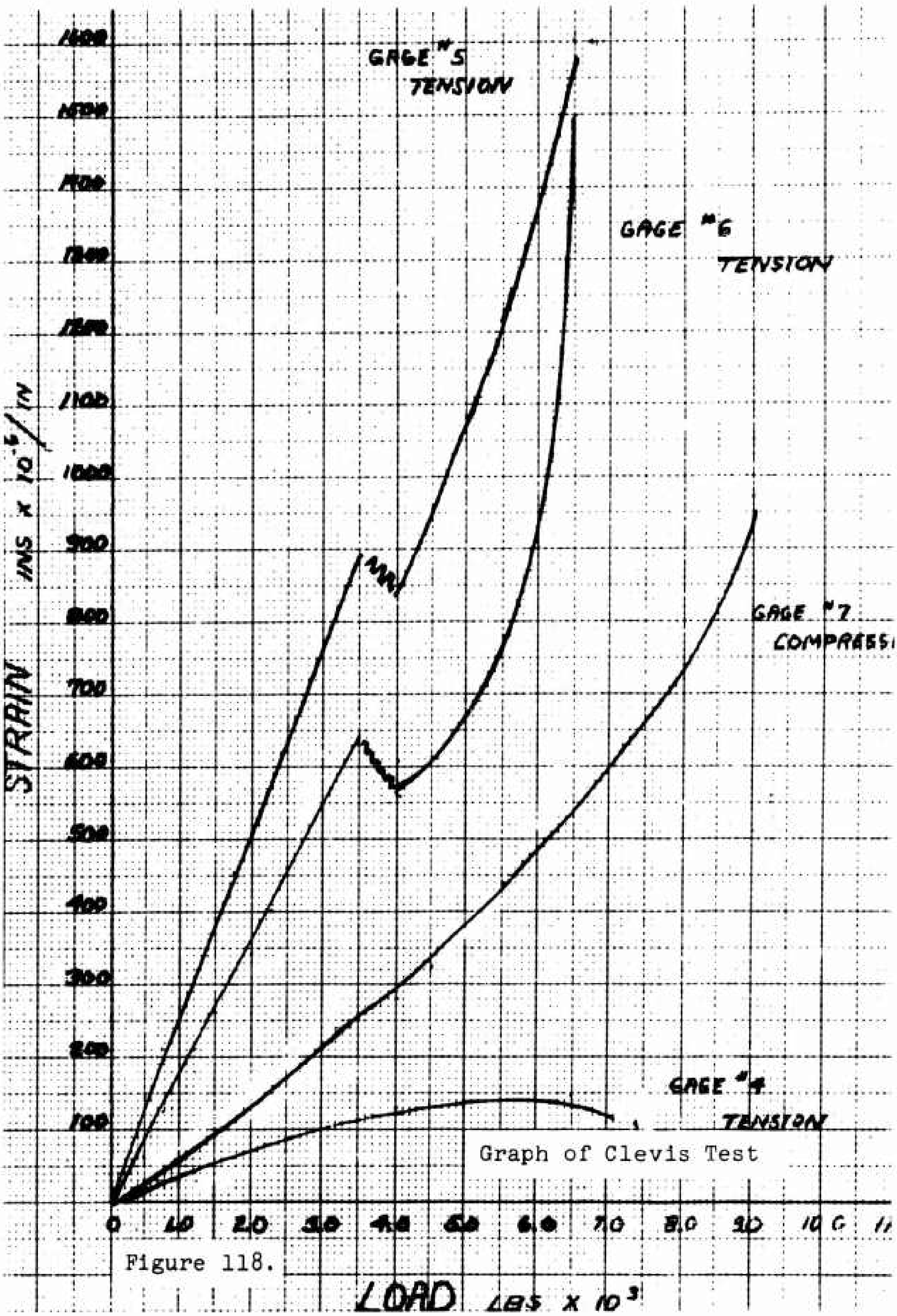

GAGE #5
TENSION
GAGE #6
TENSION
GAGE #7
COMPRESS
GAGE #4
TENSION
STRAIN INS x 10⁻⁶/IN
LOAD LBS x 10³
Graph of Clevis Test

Figure 118.

A. BASE PAD - Case 1

1. Initial Clevis Assembly

Two clevis assemblies were evaluated for this configuration (Fig.113). The clevis, screw, wedge plate, and base plate assembly were mounted to a support fixture designed to apply a compressive load slightly off the main screw axis. For the first test of this assembly, six (6) C-19 strain gages were mounted on the clevis and one (1) on the wedge plate. The gages were all single axis and orientated as shown in Figure 113. Readings taken on these gages are shown in Table I and appropriate graphical representation presented in Fig. 117 and 118.

Failure of this unit was identified at an applied load of 11,000 pounds. The clevis deformation was of such a magnitude that the strain gages selected were not capable of sufficient elongation to adequately monitor the entire test.

The bolt connecting the clevis and triangular hinge was also bent. The actual test set up is shown in Figure 119,the deformed clevis in Figure 120.

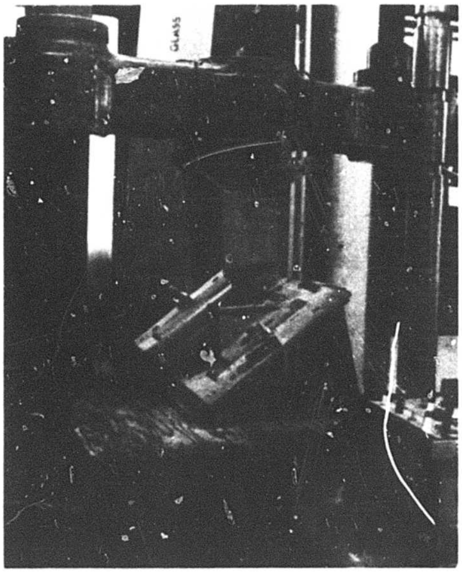


Figure 119. First Test of Clevis

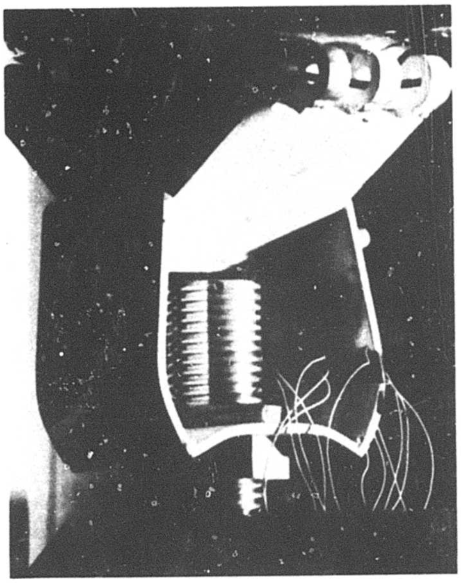


Figure 120. Bending of Clevis During Test

2. Modified Clevis Assembly

A modified clevis was also tested. The second unit was constructed of 3/8" steel plates with an additional 1/4 inch spacer and is shown in Figure 121.

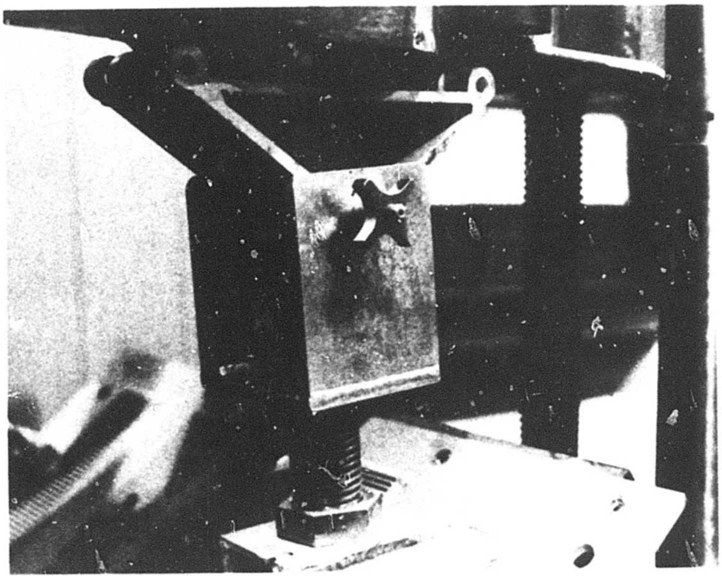


Figure 121. Modified Clevis Assembly

The modified clevis assembly obtained and applied a load of 21,500 pounds. At this point a shear failure of the bolt connecting the clevis and the triangular hinge was detected at a load of 20,000 pounds but had not become critical.

Upon disassembly of this unit, it was found that the bolt hole in the triangular hinge adapter had elongated. The approximate dimensions of the resulting hole are shown in Figure 122.

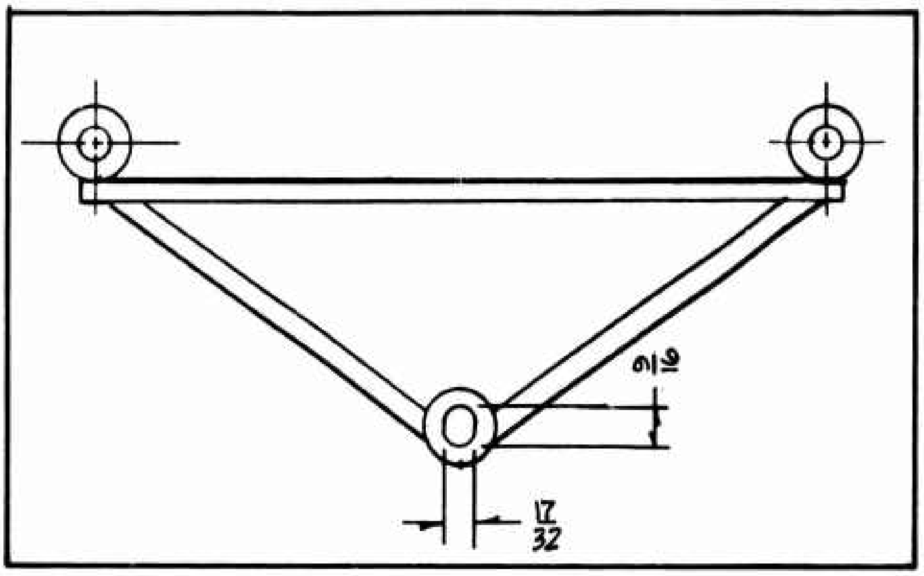


Figure 122. Triangular Hinge Adapter Showing Elongated Bolt Hole

3. Conclusion

The modified clevis was a considerable improvement over the initial design tested. Whereas the first assembly experienced a failure due to plate deformation in the clevis, the modified unit clearly experienced failure due to shearing of the bolt.

The modified unit performed satisfactorily at the design load of 16,600 lbs. as specified. However, failure occurred at 21,500 pounds,considerably less than the desired goal of 2.5 times the design load.

The assembly could achieve higher load capacity by using a higher strength (and higher cost) bolt. However, it is felt that an impending clevis collapse may also require strengthening the spacer plate or modification of the clevis design to obtain a significant overall improvement of the base pad assembly. Also, the elongation detected in the triangular hinge adapter bolt hole will require attention to achieve significantly higher loads. Therefore, if performance in the area of 20,000 to 25,000 pounds is satisfactory, the bolt failure may be delayed by making two design refinements. First, bolt shear was experienced primarily at the threaded end suggesting that if the threads can be limited to that portion required for the nut and part of the clevis wall, but not extending into the hinge-adapter interface, failure can be delayed. Second, and for the same reason stated above, the bolt which is currently a course thread should be changed to a fine thread. The fine thread will result in improved strength.

The above mentioned suggestions were considered and incorporated in the final designs with a change in material to a high strength stainless steel.

B. BASE PAD - Case 2

1. Initial Clevis Assembly

As was true of Case 1 for the base pad, 2 units were tested. The first employed a clevis assembly identical to that used for the initial test under Case 1 and the second employed a modified version. The general orientation for both tests is shown in Fig. 114. The actual test set up for the first unit is shown in Figures 123 and 124.

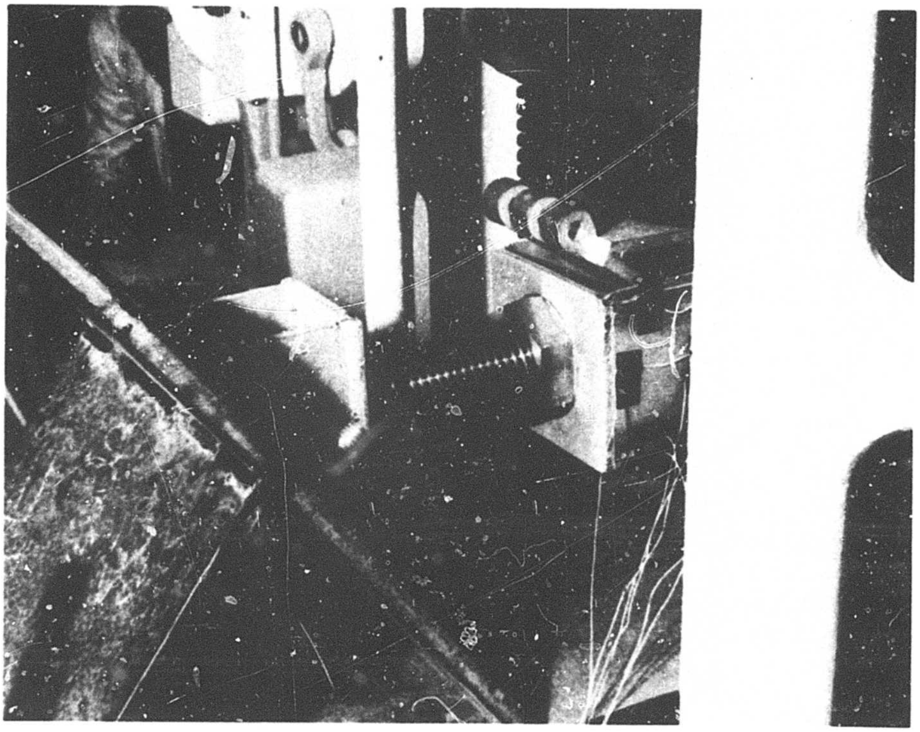


Figure 123. Test Set-Up Main Adjustment Screw

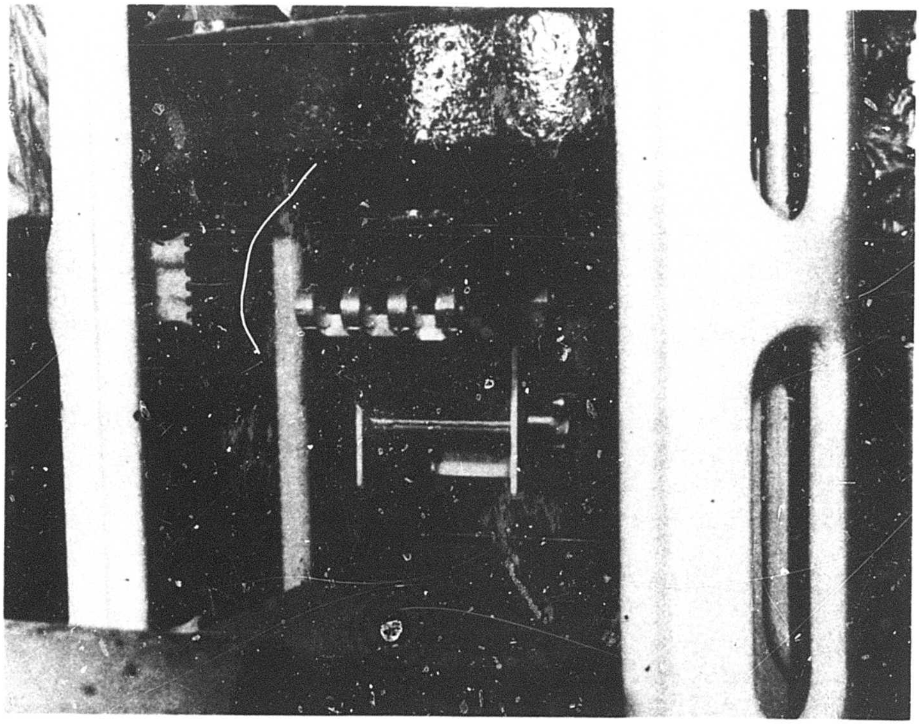


Figure 124. Test Set-Up Main Adjustment Screw

The deflection of the bolt connecting the triangular hinge and clevis was monitored and is presented in Table II. The test was halted at a load P = 2100 lbs. At this point, the main screw assembly had deflected a sufficient amount, such that the triangular hinge adapter,which was being employed to load the structure, had rocked back into contact point A in Figure 125.

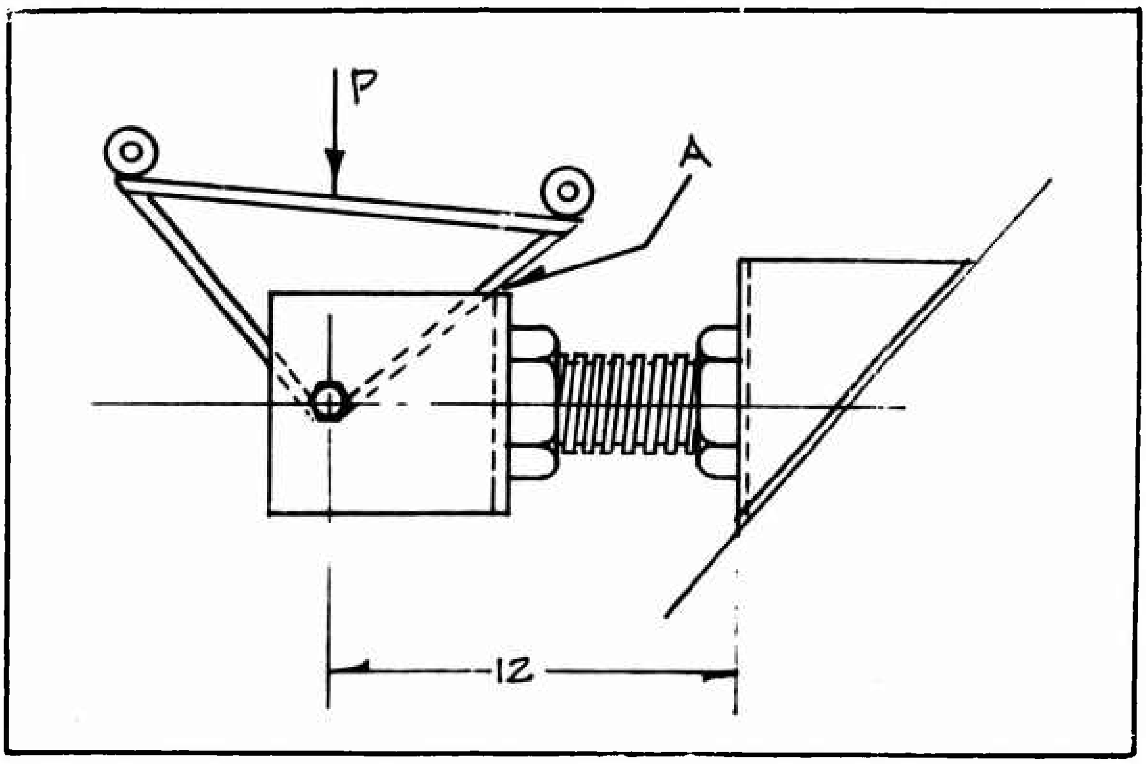
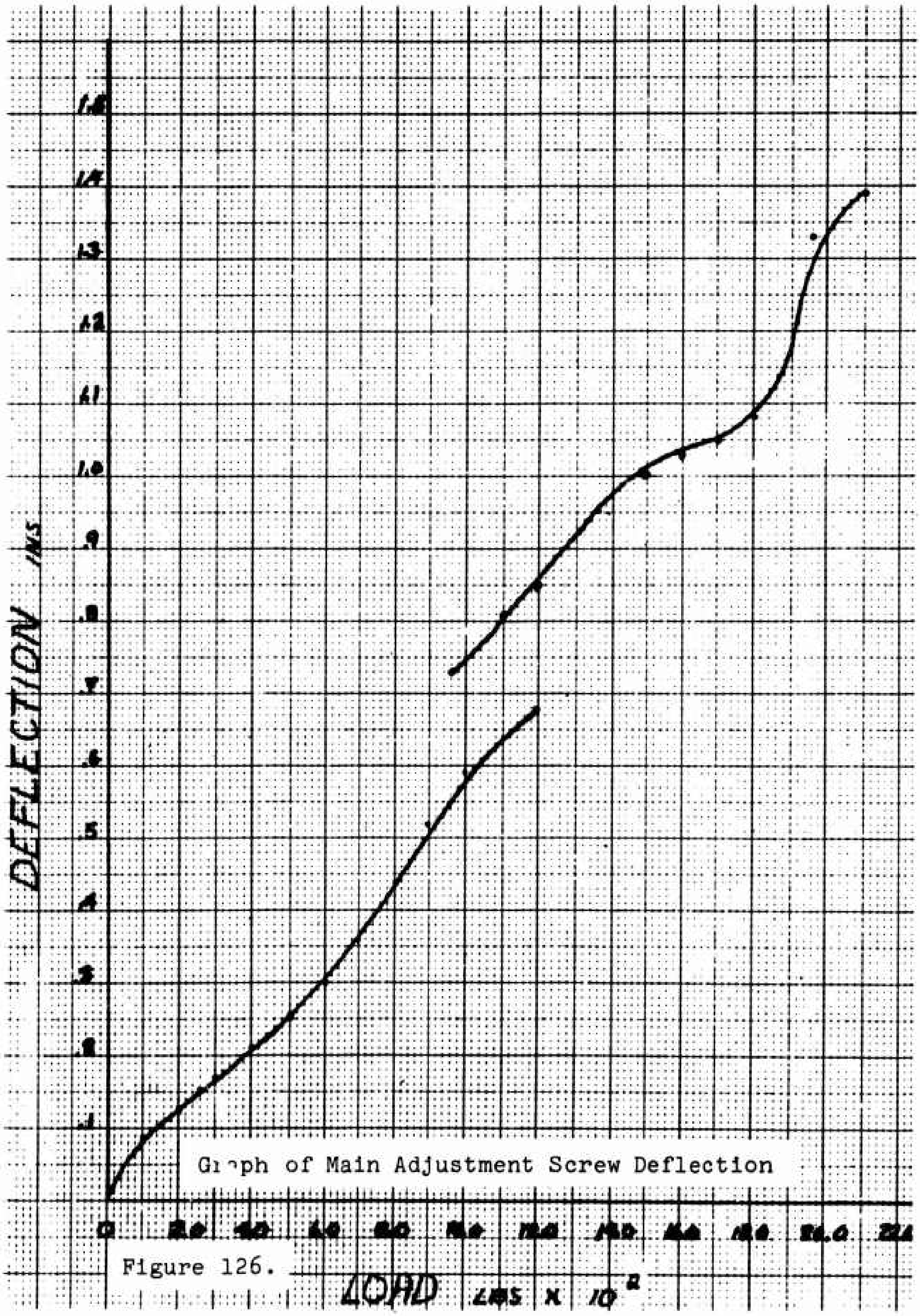


Figure 125. Deflection of Main Adjustment Screw



Graph of Main Adjustment Screw Deflection

Figure 126.

TABLE II-A

LOAD	DEFLECTION (INS.)
0	0
100	.08
200	.12
260	.15
300	.17
400	.21
500	.25
600	.30
700	.36
800	.44
900	.52
.985	.57
1000	.59
1200	.68
960	.73
1100	.81
1200	.85
1350	.98
1500	1.01
1600	1.03
1700	1.05
1800	1.08
1900	1.19
1960	1.33
2100	1.39

Upon disassembly of the unit, it was found that the wedge face plate had bowed and separated somewhat from its sides. In addition, the main screw which is welded to a base nut fitting inside the wedge, had started to break this weld and was cocked with respect to this nut. The wedge and main screw are shown in Fig. 127. The bolt is from Case I, compression loading of clevis.

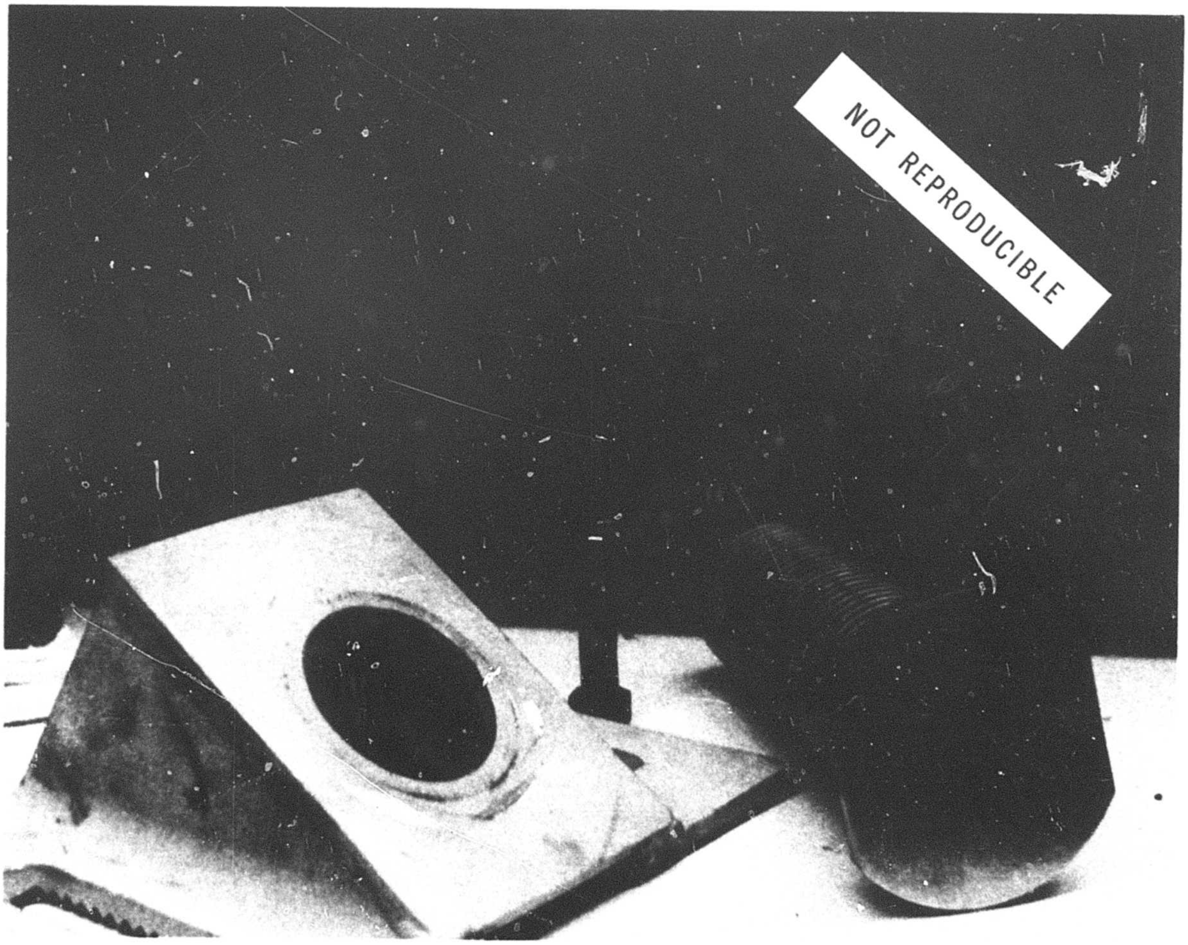


Figure 127. Main Adjustment Screw and Wedge After Test

2. Improved Wedge Assembly

The test of the Case 2 base pad configuration was repeated using an improved wedge and main screw nuts. However, in this case the triangular hinge adapter was bypassed and the load applied directly to the clevis. This procedure eliminated the problem of the hinge contacting the clevis base.

The test set up is shown in Fig. 128 and the clevis deflection versus load history presented in Table III and Figure 129.

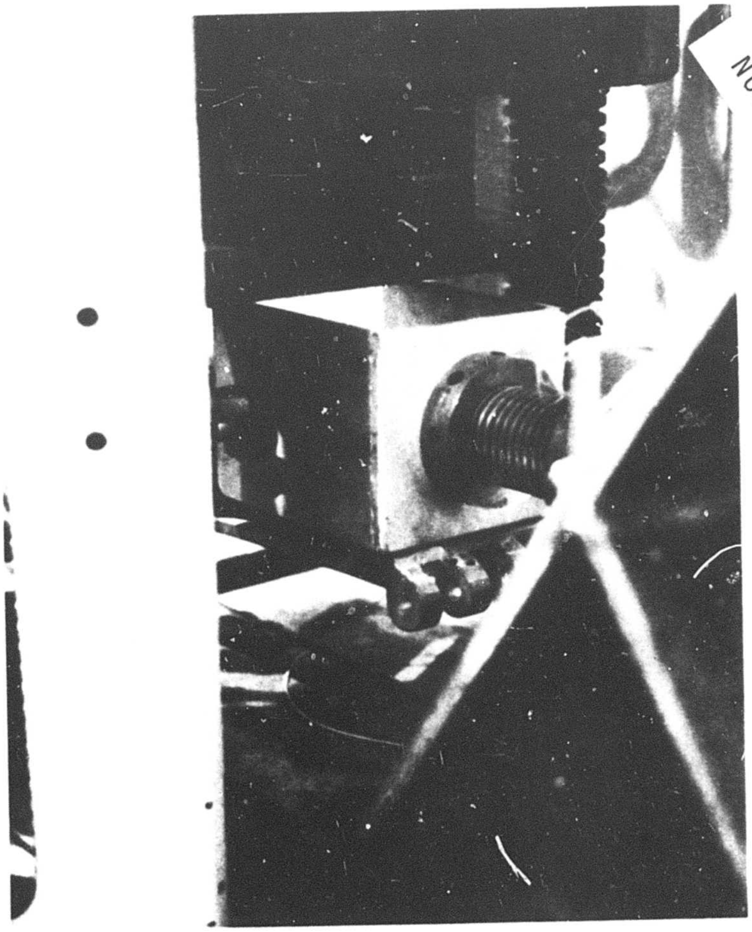


Figure 128. Improved Wedge Assembly

TABLE III

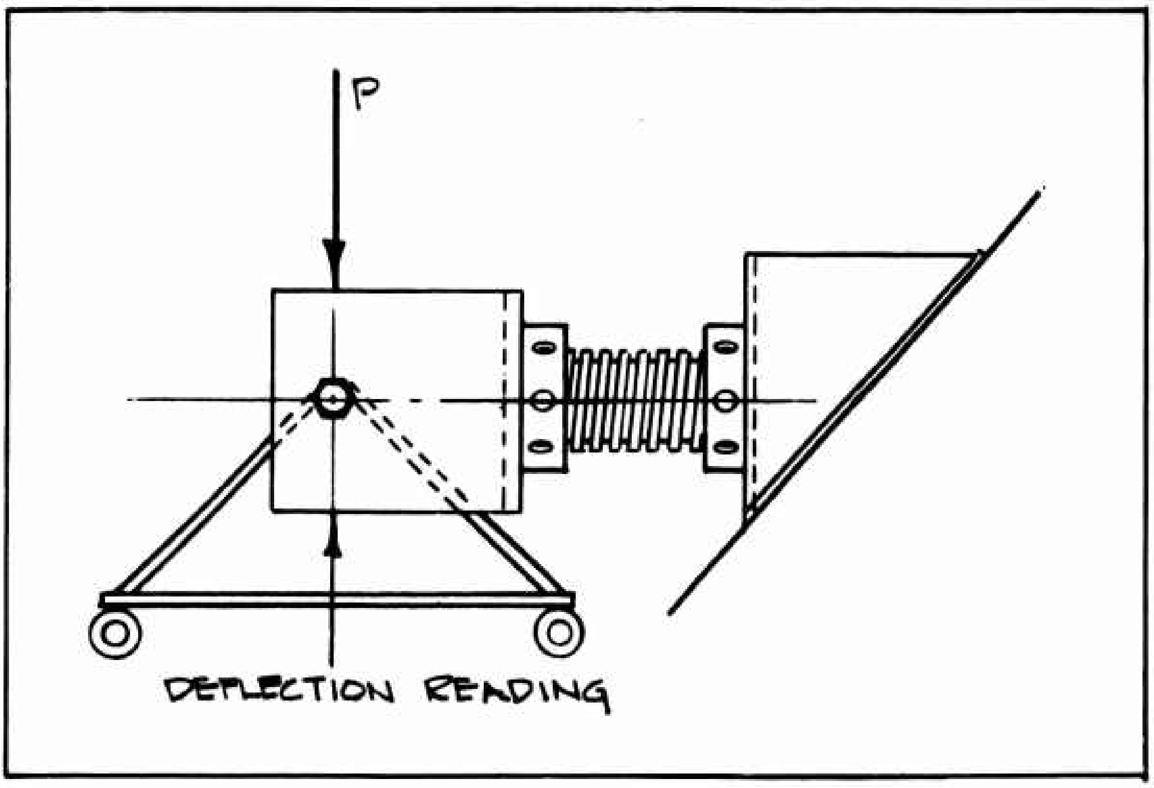


Figure 129. Improved Main Adjustment Screw Test Set-Up and Deflection Reading

DEFLECTION READ

Load (lbs)	Deflection (in.)
100	0.100
1420	0.42
1690	0.47
1850	0.50
2100	0.56
2300	0.62
2600	0.72
2700	0.75
2800	0.77
2900	0.79
3000	0.84
3100	0.90
3200	0.93
3300	1.08
3300	1.11
3380	1.22

This clevice (aluminum) went to 3,400 pounds.

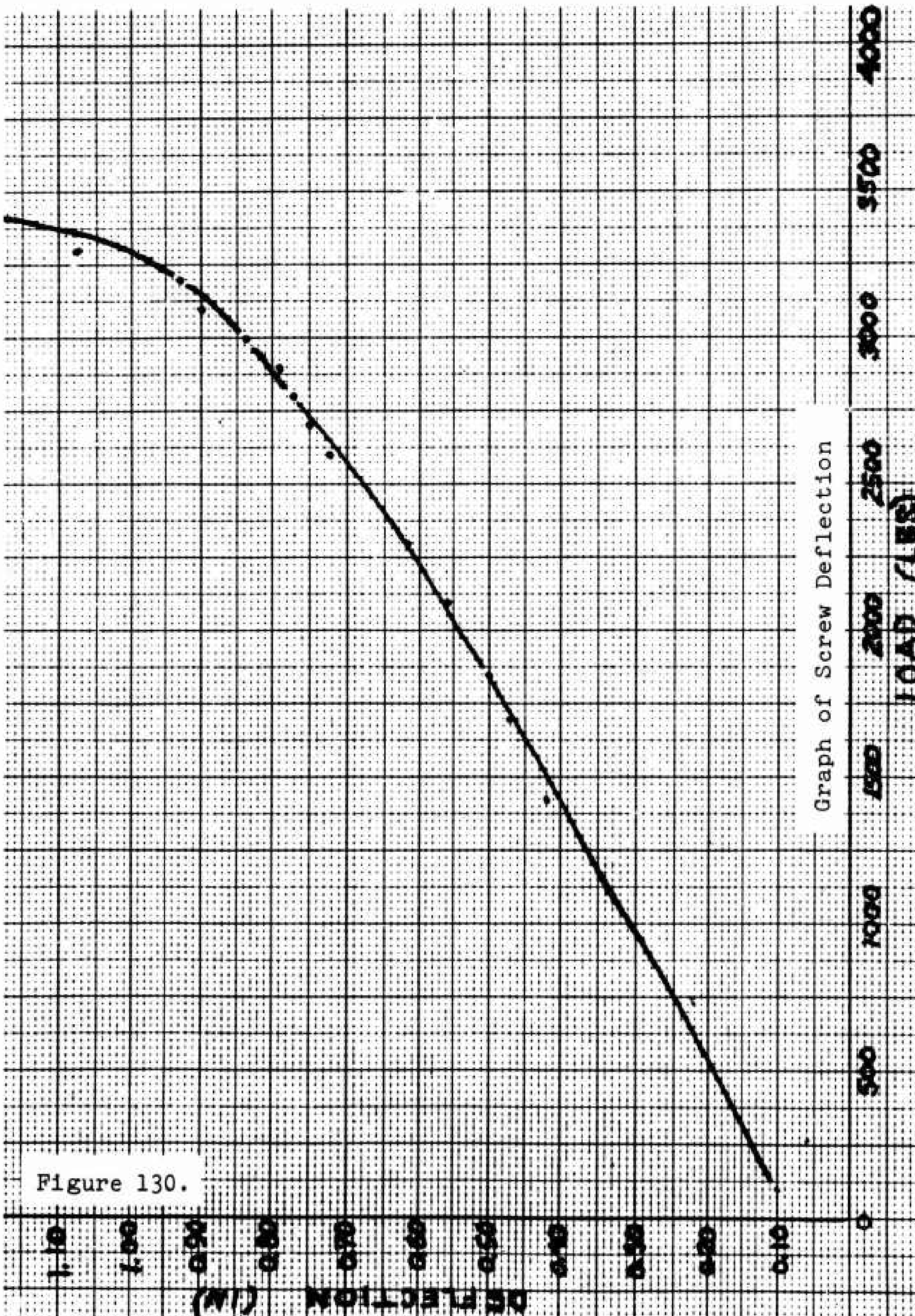

Graph of Screw Deflection
LOAD (LBS)
DEFLECTION (IN)
0
500
1000
1500
2000
2500
3000
3500
4000
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10

Figure 130.

Failure was detected at an applied load of 3,400 pounds.

The test was repeated using a new clevis assembly. The deflection load data is shown in Table IV. Failure in the form of a crack in the weld joining the wedge face plate and wall was detected at an applied load of P = 3900 lbs.

TABLE IV
(See Table III Sketch)
New Clevis

Load (lbs)	Deflection (in)
100	.30
200	.44
300	.45
400	.47
500	.48
600	.51
700	.53
800	.55
900	.57
1000	.60
1170	.62
1300	.64
1400	.66
1500	.67
1600	.68
1700	.70
1800	.71
1900	.73
2000	.74
2100	.75
2200	.76
2300	.78
2400	.79
2500	.80
2600	.81
2700	.82
2800	.83
2900	.84
3000	.86
3100	.87
3200	.87
3300	.89
3400	.90
3500	.92
3600	.95
3700	.98
3800	1.03
3860	1.10
3900	1.12

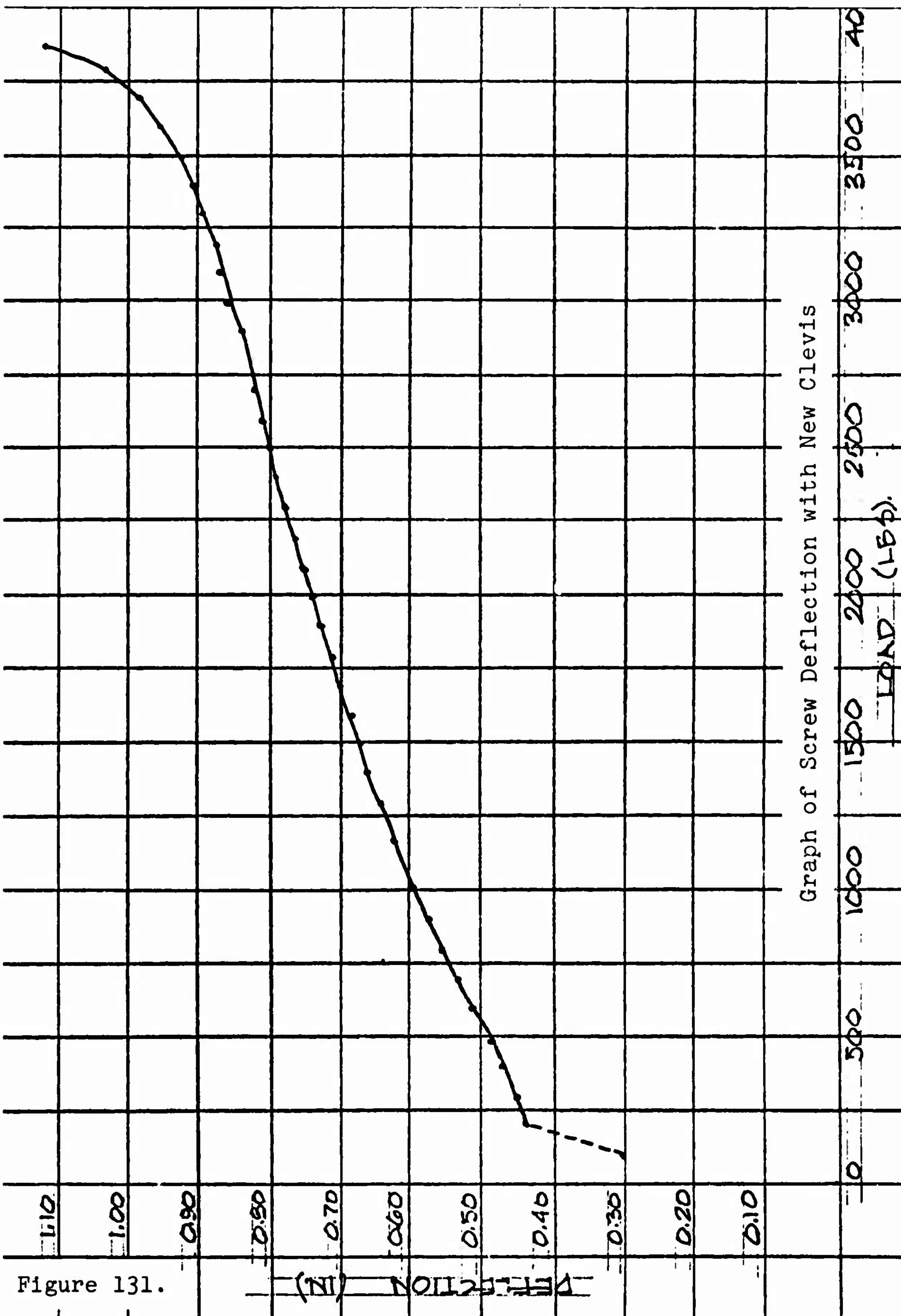

Graph of Screw Deflection with New Clevis
LOAD (LBS)
0
500
1000
1500
2000
2500
3000
3500
40
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
DEFLECTION (IN)

Figure 131.

3. Conclusions

The Base Pad assembly was able to withstand the design load of 3160 lbs. but failed to achieve a 2.5 design overload.
To improve performance will probably require achieving additional performance from both the wedge (particularly its joints) and the base of the main screw. The situation is complicated by the fact that ideally the wedge should be welded on the inside of the joints as well as the outside, but that a bead on the inside will interfere with uniform fit of the main screw base as currently designed. It is true that a continuous bead can not be welded on the inside joint of the wedge. However, a one (1) inch bead was placed at the four (4) corners and eliminated the cracking experienced in this second test.

C. Hinge Test

1. Initial Hinge Test Beam

The hinge beam test was designed primarily to investigate the failure mode and operating limits of the hinge assembly.

In the first case tested (Fig. 115), the beam assembly was placed in the machine in a V orientation. The approximate dimensions for load application are shown in Fig. 115 with D = 48", S = 13 1/4".

A trial load of P = 30,000 lbs was applied. The unit was partially disassembled, and inspected for impending failure. During this inspection, the hinge at "A" in Fig. 115 was removed, the bolts, hinge holes, and beam holes showed no indication of having been under load. It is estimated that the moment at the beam interface (a couple transmitted between the two beam members by their own contact and the hinges) was approximately 260,000 in-lbs for this trial case.

$$(D/2 - \frac{S}{2}) \quad (\frac{P}{2}) \quad = \quad (24\text{-}6\ 5/8) \quad (15000) = 260{,}000 \text{ in-lbs.}$$

Unfortunately, the bottom or tension hinges were not examined.

The unit was then re-assembled and tested to failure which occurred abruptly at a load P = 37,470 lbs or about 325,000 in-lbs at the beam section interface.

The failure was due to complete shearing of the four 1/2" bolts holding the tension hinge at location B in Figure 115. The beam is shown in Figs. 132 and 133.

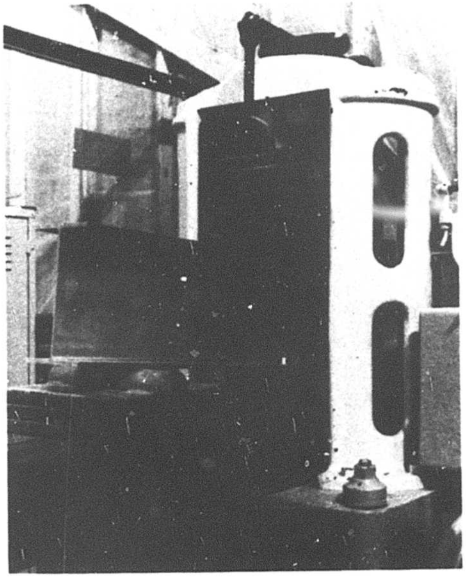


Figure 132. Main Arch Beam Hinge Test Set-Up

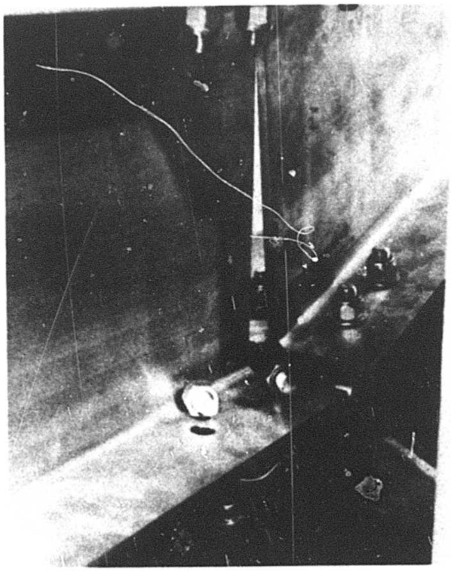


Figure 133. Shearing of Bolts During Testing

2. Hinge-beam Test with High Strength Bolts

The hinge-beam test was repeated after substitution of the original hinge bolts with high strength bolts (class 5) of the same diameter. However, for this series of tests, the assembly was inverted and tested as shown in Fig. 116. This orientation was felt to produce a loading condition more characteristic of the assemblies anticipate environment.

Two tests were conducted with the assembly in this orientation. The first is shown in Fig. 116 , with D = 58 1/2" and S = 13 1/4" and in Figure 134 .

Failure in this case occurred at a maximum load of P = 33,160 lbs and was due to a twisting of both beam sections. This tendency was first observed at a load of P = 28,000 lbs and is shown in Fig . 135 . The estimated moment at the beam interface for this failure is:

$$\left(\frac{D}{2} - \frac{S}{2}\right) \left(\frac{P}{2}\right) = \left(\frac{58\ 1/2}{2} - \frac{13\ 1/4}{2}\right) \left(\frac{33{,}160}{2}\right) = \underline{375{,}122 \text{ in-lbs}}$$

A second test was conducted in this orientation (inverted V) but with the supports moved in. This was done in an effort to produce a more stable beam configuration and develop the desired loading of 420,000 in-lbs at the beam interface. The relevant dimensions for this case are shown in Figure 116 with D = 32" and S = 13 1/4". The test set up is shown in Figure 136.

Once again, failure occurred due to beam twisting at a load of P = 75,000 lbs. The initial tendency to twist was detected at a load of P = 48,000 lbs. The moment at the interface corresponding to the failure load of P = 75,000 lbs is:

$$\left(\frac{D}{2} - \frac{S}{2}\right) \left(\frac{P}{2}\right) = \left(\frac{32}{2} - \frac{13\ 1/4}{2}\right) \left(\frac{75{,}000}{2}\right) = 352{,}000 \text{ in-lbs.}$$

A preliminary inspection of the hinge assemblies, pins, and bolts did not reveal any significant deformation.

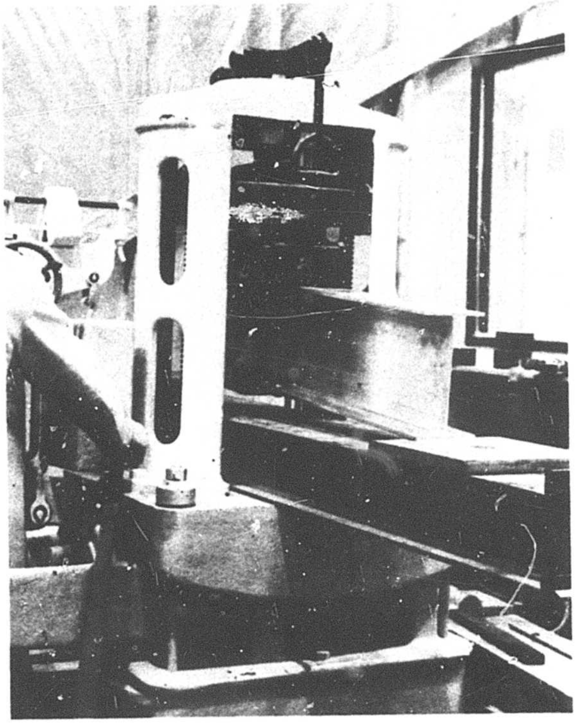


Figure 134. Improved Test Set-Up Using High Strength Bolts

Figure 135. Twisting of Beam During Test

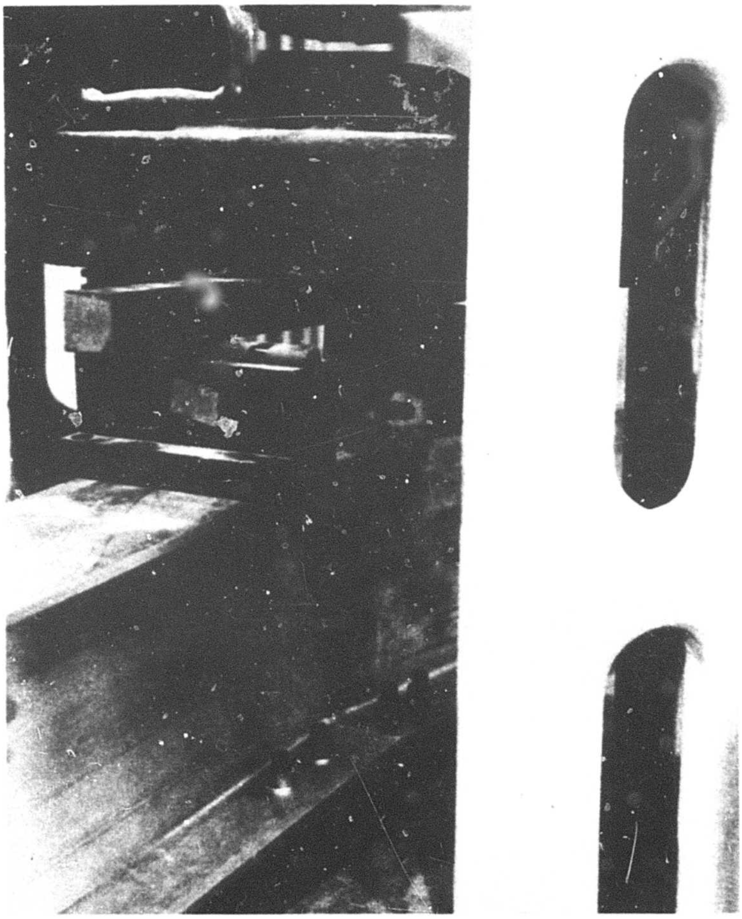


Figure 136. Second Hinge Test With Supports Moved In

3. Conclusions

The replacement of the 1/2" coarse thread, mild steel bolts by 1/2" fine thread, high strength bolts appears to have significantly elevated the structural integrity of the hinge assembly.

The tendency of the I beams to be relatively weak in torsion prevents testing of the hinge assembly to failure but raises some question as to the beams capability. However, it is impossible to assess the importance of their lack of torsional rigity without evaluating their role in the structure and the types of load predicted for them.

The hinges appear to be superior to the beam with the limiting factor being failure due to shearing of the 4 bolts joining them to the beam sections. In the final assembly, a C 8 bolt was used for attachment of hinges. This bolt gives the maximum strength at this diameter.

VIII

BIBLIOGRAPHY

Aluminum Company of America, Pittsburgh, 1966, Alcoa Handbook of Design Stresses for Aluminum

Aluminum Company of America, Pittsburgh, 1966, Alcoa Structural Handbook

Aluminum Company of America, Aluminum Properties, Three (3) Volumes, Editor, Kent R. Van Horn, Published by American Society for Metals.

American Institute of Steel Construction, Inc., New York, 1967 Manual of Steel Construction

Firmage, D. Allan, Fundamental Theory of Structures, John Wiley and Son, Inc., New York and London 1963

Massachusetts Institute of Technology, School of Engineering, Ices Strudl-I, Volume I, Frame Analysis

Owen, John B., The Analysis and Design of Light Structures, American Elsevier Publishing Company, New York, 1965

Rubenstein, Mosbe F., Matrix Computer Analysis of Structures, Prentice-Hall

University of Toronto Press, Toronto, 1968, Wind Effects of Buildings and Structures, Proceedings of the International Research Seminar held at the National Research Council Ottawa, Canada, 11-15 September 1967, Volumes I and II.